SCIENCE, TECHNOLOGY AND ARCTIC HYDROCARBON EXPLORATION : *THE BEAUFORT EXPERIENCE*

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WITH THE ASSISTANCE OF [illegible]RUCE E. DEMCHUK

SYMPOSIUM PROCEEDINGS

34th Alaska Science Conference

Whitehorse, Yukon, 1983

Arctic Division - American Association for the

Advancement of Science

86-0125/

SCIENCE, TECHNOLOGY AND ARCTIC HYDROCARBON EXPLORATION : THE BEAUFORT EXPERIENCE

PROCEEDINGS OF A SYMPOSIUM
held at
34TH ALASKA SCIENCE CONFERENCE
WHITEHORSE, YUKON
SEPTEMBER 20 - OCTOBER 1, 1983

ORGANIZED BY

MAJOR PROJECTS BRANCH
DEPARTMENT OF ECONOMIC DEVELOPMENT
GOVERNMENT OF YUKON

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1984

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ACKNOWLEDGEMENTS

The first thought of discussing the scientific and technological aspects of Arctic oil and gas exploration at the 34th Alaska Science Conference came in the Spring of 1983. The idea of the symposium took form during a conversation between Bill Oppen and myself. The conversation was started by Bill. He was extremely enthusiastic about the "Beaufort Science Symposium" and he and I were co-chairmen of the symposium during the early planning stages. Bill later took over the responsibilities of Conference Arrangements Committee Chairman. However, his influence on the form of the Beaufort Symposium is substantial and the present volume owes much to his work.

Art Pearson and all of the conference committee members contributed greatly to the symposium. Rusty Reid, in particular, provided much on-the-spot help.

The symposium banquet, organized by Ken McKinnon and held jointly with participants in the Caribou and Human Activity Symposium, involved the help and co-operation of Art Martell and Don Russell.

Two primary objectives in organizing the symposium were to include U.S. as well as Canadian presentations and to review work which, although not carried out in the Arctic, could provide some perspective on Arctic oil and gas activities. Both of these objectives were realized through quality contributions summarizing research and technological work conducted in areas as geographically diverse as the Bering Sea, Ontario and the Mackenzie Valley. Acknowledgement is due not only to the symposium participants whose work is published in this volume, but also to those whose presentations were not available for inclusion in the book, Steve Blasco, Alan Judge and Alan's colleagues.

Murray Todd, Senior Vice-President, Dome Petroleum and Dr. George Calef, wildlife biologist and naturalist photographer, were informative and entertaining guest speakers at the symposium banquet. (Don Russell stole the show with his stand up commentary on the quality of the wild game that was served.)

Dick Hill, a scientist who has lived in Inuvik since the 60s, participated throughout the symposium, chaired the sessions on the final day, and provided a comprehensive, integrated and insightful wrap-up commentary.

Grateful appreciation is due the Government of Yukon, Dome Petroleum Ltd., Gulf Canada Resources Inc., Esso Resources Canada Ltd., and Petro Canada Ltd. for their sponsorship of the symposium.

The reports in Part Three of this collection were reprinted with permission. Thanks go to Bill Pistruzak of Dome and Sharon Hillman of Sohio, Alaska, for providing the material and the green light to include it here.

Bruce Demchuk landed behind the scenes at the symposium with the first session just days away. His contribution since has been tremendous.

Maureen Fontaine will be glad to see this manuscript on the road to the printers. She has spent many hours typing a number of the papers.

Any errors, oversights or omissions that remain in the text are my responsibility.

Tim McTiernan
May, 1984.

PART ONE

INTRODUCTION:
SCIENCE, TECHNOLOGY and the ARCTIC CONTEXT

The introductory papers in this collection are intended to set the stage and provide a general context for the work that is organized in later sections. The first of the two papers is contemporary in orientation. The second is historical. Together they advance a two-point argument. Present scientific research and technological innovations in support of northern oil and gas activities have their roots in a succession of exploratory drives into the Arctic to define and extract its various resources, from fools gold to black gold. The pathways along which future advances in industry-oriented science and technology will move will be shaped as much by broad policy decisions regarding the role of the north in a changing Canada as they will by the pure mechanics of doing science or developing technology.

McTiernan, in describing the way in which the "Beaufort Science Symposium" took shape, outlines some of the social, political and cultural perspectives that are brought to bear on oil and gas activities in northern Canada and that can affect scientific and technological programmes in support of those activities.

Pallister, in a backward look at the evolution of scientific research and the application of technology in the Arctic, underlines the close interplay between technological innovations, the ability to do science, and the practical problems associated with resource extraction and the day-to-day efforts to work and live in a demanding environment.

SOME PERSPECTIVES ON SCIENTIFIC AND TECHNOLOGICAL WORK IN NORTHERN CANADA - THE FISHBOWL PHENOMENON

TIMOTHY J. McTIERNAN

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Northern residents might argue that one can recognize the onset of spring by two waves of migration. First one hears the high-pitched cries of the birds as they leave their resting places in the early morning to fly north in deep V formations. A month or six weeks later, even two or three months depending on the location, come the researchers. They are a noticeable and significant social phenomenon as they load their equipment and gear into four wheel drive trucks, transfer it to float planes and ski planes, stow it on boats, and head to their field camps, research institutes and study sites. Their presence across Yukon and the NWT is monitored with interest and can generate strong feelings and strongly ambivalent attitudes.

The study of issues as diverse as early human actvity in the Old Crow Basin and bird behaviour in colonies in Lancaster Sound can reinforce residents' sense that the north is a special place in which to live. Southern experts' attention to water flow and break up patterns in the Mackenzie River system and to the problems of developing municipal services in permafrost zones can leave a residue of frustration because it can underline the fact that regional expertise in such areas is often thin on the ground.

Summer research projects can provide welcome work to local residents. Students can collect data. Northern businesses can provide goods and services. Aircraft charter companies can provide helicopters and fixed wing transportation. Yet there is an awareness that the longer term implications of such research programmes could alter the entire fabric of northern life. A fear of some residents is that they will be left on the outside, looking over the fence as roads and pipelines cut across the landscape, as ships move through the Arctic Archipelago on a year-round basis, as the larger northern towns grow even bigger at the expense of the smaller, longer established communities, and as mines, harbours, oil and gas production facilities and airports are developed in the national interest.

Indeed, northerners are particularly sensitive to the possibility that the Canadian Arctic and sub-Arctic can be seen as a vast laboratory filled with social, biological and physical science data to be exploited at will by colonially-minded, southern-based "experts" who have very little real investment in the social and political aspirations of northerners. They are concerned, also, about the consequences of specific research programmes in that such work may result in development activities that will radically change the lifestyles so highly valued by long term and short term residents alike.

Such perspectives may not often be well founded. Certainly they are not held by all northern residents. They do, however, form a strong backdrop to scientific and technological research in Canada's north. They create the "fishbowl phenomenon", the fact that scientists and technologists working on "northern problems" are observed intently, and that, however impartially their courses of study are pursued, the results are reviewed, screened and reacted to by a population with sharply defined political, social and cultural values and aspirations. Nowhere is this fishbowl phenomenon more apparent than in work related to oil and gas exploration in northern Canada.

Science, Technology and Oil and Gas in the Arctic

It is a cliche to say that the scope and depth of scientific and technological work in the Arctic is overwhelming, but it is a true cliche and it needs to be restated from time to time.

Seldom is the full range of Arctic research hushed into the public view, As a result, it is easy to fall back on a standard image of the north as a barren, untapped land containing a few, isolated resource extraction enclaves, and sparsely populated by native Inuit and Indian peoples pursuing traditional hunting and trapping lifestyles. Other activities in the region are forgotten or largely overlooked. In contrast to this image, however, industry, government and academia, separately and jointly, sponsor research programmes that are frequently long term in scope, truly circumpolar in orientation and tremendously diverse in content. The practical outcome of some of this work has been the extension of shipping seasons in northern regions, the construction of DEW Line facilities and meteorological stations across the Arctic, the establishment of communities such as Inuvik and Resolute, the technological know-how to bring large commercial jets in and out of gravel and ice strips, and advances in telecommunications both technically and in terms of enhancing information resources in schools, hospitals and libraries in remote communities.

Hydrocarbon activities provide a framework for much that is current in this type of research in northern Canada. Indeed, in a recent edition of the APOA Review (Winter 1983/84, Volume 6, number 3) a study is cited which suggests that $3.5 billion of potential investment in new technology has been created by the Canadian petroleum industry in the period from 1969 to 1981 (Tiffin 1983).

Even a partial listing of scientific and technological innovations in the oil and gas field is impressive. Dome has pioneered the use of ice-reinforced drillships and has added state-of-the-art icebreakers to its fleet. Panarctic has developed and field tested a prototype subsea natural gas production system, and the company continues to refine its techniques for drilling from stable, reinforced sea ice platforms. Petro-Canada's Arctic Pilot Project proposal to ship gas from the Arctic Islands has resulted in design advances for LNG tankers. Esso has spearheaded the engineering of drilling islands, first with its sandbag retained platforms, then with its sacrificial beach islands, and later, in parallel with Dome's and Gulf's versions of the system, with a caisson-retained structure. Moreover, Esso, in increasing its production from northern Canada's only developed field, has constructed enhanced recovery facilities at Norman Wells. Gulf, for its part, has built an integrated, third generation drilling fleet for the Canadian Beaufort that will push out the offshore drilling season far beyond the capabilities of the more conventional drillships. On land, Foothills has had an active research programme on pipeline installation procedures in intermittent permafrost zones.

At the same time, work on oil spills and clean-up measures, ice strength, permafrost drilling fluids, safety and remote medicine, winds and currents, pipeline and marine transportation corridors, navigation aids, climate information systems, ice-drilling platform interactions, dredging techniques, forecasting, ice rubble generation, and marine and terrestrial biological systems is being intensified by groups of government, industry and consultant scientists.

The Alaska Science Conference symposium on Science, Technology and Arctic Hydrocarbon Exploration: The Beaufort Experience was organized to capture the flavour and highlight new directions in some of these broad reaching scientific and technological programmes. The focus was placed on operations in the Canadian Beaufort for parochial reasons and because of current events surrounding the timing of the conference.

The parochial reasons relate to the fact that Yukon's involvement in oil and gas activities is mainly through operations in the Beaufort Sea and, as a result, it is hard for us in Yukon to remember that the Beaufort is not the beginning and end of northern Canadian exploration activities. Our focus on the Beaufort in the summer and fall of 1983 was well placed, however, because Esso was getting ready to use its steel caisson island, Dome was preparing for a second winter with its moveable steel drilling caisson, the SSDC, and Gulf was bringing its new fleet in to work its acreage and was looking for a land site from which to support its offshore activities.

Nevertheless, while the focus of the symposium was on Beaufort operations, strong efforts were made to balance the sessions with presentations on work being carried out in other Canadian and U.S. regions to provide a historial perspective on the general theme, and to consider research and development in other industries that could be applied usefully in the hydrocarbon field.

Thus the symposium programme brought the participants from 30,000 years ago through reviews of island technology, drilling systems and production concepts, to discussions of ice-breakers, monitoring and data distribution systems, oil spill research, underwater photography, ice research, and the problems of determining peak water levels at spring breakup. Going beyond the Beaufort and oil and gas issues, the final paper in the collection suggested ways in which R & D from the nuclear industry could be borrowed by other sectors such as the hydrocarbon industry.

Science, Technology and the Northern Context

The social, cultural, environmental and political issues that northerners often maintain are background factors to the work represented in this volume are never far from public discussion.

There are recurrent questions about the social implications of industrial activities in the north at environmental assessment review hearings, at industry meetings with communities, and at land claims workshops. Concerns are raised about alcoholism, suicide and family problems associated with the buying power of industry pay cheques. The spectre of economic bad times following the boom is heavily emphasized. Overall, there is a deeply held feeling that resource development, and the scientific and technological research programmes associated with such development, are contributing substantially to the forces that are inexorably altering the fabric of northern society. In a strong attempt to deal with the good and the bad that changing lifetyles will bring, there is a firm drive for more regional input and control over decisions regarding the permitting and regulation of industrial programmes in northern Canada. This drive for input, more and more, is beginning to encompass basic as well as applied scientific studies.

Concern over the impacts and end results of scientific and technological research is especially marked in the case of environmental issues. Debate and argument is fueled by at least three different perspectives related to an acceptable balance between resource development and the preservation of regional ecosystems and significant wildlife species such as the caribou, whales and migratory birds. On one wing are the advocates for total protection of large areas of the northern environment. These advocates emphasize the unmeasureable wealth of an undisturbed wilderness. Their view is as much an aesthetic one as it is a biologically oriented or an ecologically oriented one. On the other wing are those who believe that, with sufficient care and attention, any environmental problems that occur as a result of human disturbance to the locale can be solved by applying good scientific and technological principles. From this perspective, the strict regulation of industrial projects is overly restrictive and leads to unnecessary costs since mistakes in development programmes can be corrected as soon as they are detected. The third viewpoint in the environmental forum emphasizes the value of environmental management and the need to weigh and balance economic and environmental interests in resource development decisions. Because these perspectives are just that, perspectives, none will predominate nor supplant the others purely on the strength of research evidence and study findings. The debate between the various advocates will continue throughout the lifecycle of various project development proposals.

There are, then, two volatile policy arenas, social policy and environmental policy, that are exerting pressure and will continue to exert pressure on northern resource development activities and on the research programmes supporting such activities. These policy fields interact with policy considerations regarding the national and regional requirements for building up scientific data bases in the north, in the words of the National Energy programme, "the need to know", and with policy considerations regarding the importance of development state-of-the-art technology that has an international market value.

The four general policy fields provide a fluid and a challenging environment for long term research programmes in the north. Policy choices in any one of these areas will radically affect the range, pace and nature of many future scientific and technological research programmes in Yukon and the Northwest Territories. The challenge for researchers will be to work within the policy framework to conduct their studies in a way that will not jeopardize the continuation of their projects due to the opposition of regional opinion leaders. For, increasingly, input to overall policy decisions on northern science will come from northern residents and these residents are consciously casting off the old definition of northerners as living in families with parents, children, extended kin and an anthropologist, and are, in a very deliberate way, beginning to look back at researchers and their various projects through their own finely ground critical and evaluative microscopes and observation lenses.

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THE DEVELOPMENT OF SCIENCE AND TECHNOLOGY IN THE CANADIAN ARCTIC*

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ABSTRACT

The evolution of science and technology in the Canadian Arctic has maintained a close relationship with resource development. The history of the north demonstrates that science and technology have produced solutions to the problems of living and operating in this environment.

The first immigrants to the Canadian Arctic arriving some 30,000 years ago adapted technologies and applied their knowledge of the environment to survive. The close link of indigenous people with the "land" continues to the present day.

The early European explorers sought the Northwest Passage and natural resources. Commercial activities, such as whaling and trapping, followed. The success of these ventures often depended on the quality of knowledge of the region available. Exploration and scientific pursuits by the English Admiralty and scientific societies intensified during the 1800s. In several voyages careful and detailed scientific observations and measurements were recorded. Scientific knowledge of the Canadian Arctic progressed in the first fifty years of the 20th Century aided by several significant technological developments, including improved vessel design, the development of aircraft and improved communications. Geological surveys since the mid-1950s showed the promise of hydrocarbon potential in the Canadian Arctic.

After the announced discovery of oil at Prudhoe Bay in 1968, several petroleum companies actively explored the Canadian Arctic, particularly in the Mackenzie Delta area. Soon after, exploration efforts intensified into offshore Arctic waters. This exploration, coinciding with the rise of the environmental movement, prompted the petroleum industry and government to develop the expertise for addressing environmental issues. Project assessments and approval processes by government expanded during this period. Northerners and public environmental groups became involved in the project review process.

*Presentation to the 34th Alaska Science Conference, Arctic Division, American Association for the Advancement of Science, Whitehorse, September 28 - October 1, 1983.

A significant amount of research has been undertaken since 1970 in support of Arctic petroleum operations. Key research activities have included biological, oceanographic, oil spill, ice engineering, drilling unit design and transportation studies. Several unique solutions have been attained in operating in the Arctic environment. Challenges requiring the application of science and technology to resource development remain. As the petroleum industry progresses from the exploration to production and transportation phases, additional research and development will be required to meet the goals of safe operations and environmental protection while aiding the realization of northerners' visions of their future.

Introduction

The history of the Canadian Arctic is often told as various stories of explorers and adventurers in search of new lands or of their various exploits. From a somewhat different perspective the history can be seen as the application of technology, knowledge and skills adapted to a harsh environment. Resources have figured predominately in the history as well.

This paper provides an overview of science, technology and resource development in the Canadian Arctic both past and present. Some landmarks in this history are identified and the current status of petroleum operations (especially in Beaufort Sea) are reviewed. It concludes with some thoughts on the future course of science in the north.

Earliest Residents

The earliest residents of the Canadian Arctic arriving some 30,000 years ago in northern Yukon brought with them a crude hunting technology. Successive groups brought more advanced tools, each being distinctive and progressively better adapted to the exploitation of what we now call renewable resources. On the tundra, hunters developed better ways of hunting animals such as musk-ox and caribou. The coastal peoples, forerunners of the Inuit, developed sophisticated methods for hunting sea mammals. A few examples can be mentioned. Specialized stone tools included harpoons, fish spears, and scrapes. Kayaks and sleds permitted travel over water and ice. Float harpoons were invented making hunting of large marine mammals feasible. Numerous other examples of technology could be given but the point is that the peoples' very survival depended on applying technology and skills to resource harvesting.

Historical Expeditions

Aside from the Norse, the first wave of Europeans arriving in the Canadian Arctic was led by Martin Frobisher in 1576. The early voyages of exploration had the purpose of locating the Northwest Passage and resources, resources such as gold, fur and whales. William Baffin, erroneously declaring after his 1616 voyage that no passage was possible through the northern Eastern Arctic, dissuaded further exploration by sea in the area for over 200 years. The whaling industry did, however, flourish in later years in Davis Strait. Overland journeys were attempted, with Hearne and MacKenzie reaching the Arctic coast in the Western Arctic in 1772 and 1789, respectively. MacKenzie discovered an oil seep near present day Norman Wells.

The search for the Northwest Passage by Baffin Bay resumed with John Ross' voyage in 1818. This expedition is notable for the emphasis given to scientific observations. Officers and crew were directed, "to use their utmost endeavours to collect and procure everything which may contribute to the advancement of natural knowledge." Ross returned with an abundance of information on the Inuit, animals, natural features as well as geological and hydrographic data.

From the time of Ross, the standard procedure became to keep careful records which would advance scientific knowledge and provide practical information for later voyages. The support for numerous expeditions into the Canadian Arctic came from private firms, the Admiralty and from scientific societies.

Certain learned individuals figure prominently in this era following Ross' voyage. Sir Joseph Banks, president of the Royal Society, sparked interest in the Canadian north after his visit to Labrador. Another, Sir Francis Beaufort, active in the Royal Society, Royal Astronomical Society and the Royal Geographical Society provided a link between scientists and government (the Hydrographic Office and the Admiralty) that mobilized the resources and talent for many expeditions. During this period more scientifically rigourous investigations were being assumed by specialists, rather than as in the past, when often the medical doctor on board made most of the observations.

The hazards of Arctic travel were not overcome, with several ships being caught in ice. The most notable instance was the ill-fated Franklin expedition of 1845. Subsequent searches for this expedition produced a wealth of new information on the Canadian Arctic. By 1882 the first International Polar Year commenced, leading the way for purely scientific expeditions.

By the late 1800s and early 1900s important advances in technology contributed significantly to the ability in navigating Arctic waters. Ship propulsion changed from sail to steam. Hulls were reinforced with iron plating or ribbing. Wooden hulls were gradually replaced with steel ones. And, beginning with the Fram, hulls were rounded so a vessel would rise above the ice rather than being caught and crushed in it.

In the Beaufort Sea at this time whaling peaked and declined.

The landmark Canadian Arctic Expedition led by Vilhjalmur Steffanson, undertaken from 1913 to 1918, resulted in a several scientific reports which are still of considerable value.

The rapid growth in technology, especially in aviation, ship design and communications in the past 60 years has opened up the north to researchers. Numerous government, university and international investigations were undertaken. Programs such as those which served defence requirements and meteorological needs were significant. As well, the International Geophysical Year, the International Biological Program and Polar Continental Shelf Program, to name only a few of the numerous projects, were undertaken.

Hydrocarbon Exploration

The announced discovery of oil at Prudhoe Bay in 1968 encouraged a number of oil companies to intensify exploration activities in the Mackenzie Delta and Beaufort Sea among other areas of the Canadian Arctic. At about the same time public awareness and concern for the environment grew rapidly. Public intervention in the approval process of industrial projects emerged. Both government and industry soon developed their own expertise in environmental fields such as biology and oceanography.

Since the early 1970s an intensive series of programs have been undertaken by government and industry in several fields such as:

- environmental baseline studies,
- oil spill countermeasures,
- ice research, icebreaker vessel design,
- engineering feasibility studies and,
- research into permafrost.

The oil companies, although finding hydrocarbons onshore in the Mackenzie Delta, continued the exploration offshore, where the greatest potential lay.

The principal operating constraint was the presence of ice. On the East Coast, Davis Strait, Baffin Bay and Lancaster Sound icebergs pose potential threats to safe drilling operations. Ice is also the primary limiting factor in transportation.

In the 1970s numerous ice studies were undertaken by oil companies to determine the presence of ice types and dynamics and its mechanical properties. This consisted of large-scale field tests and laboratory model testing.

Concurrent with ice research, environmental studies were undertaken. Baseline studies, inventories and studies leading to an understanding of the dynamic nature of the natural environment were undertaken. The Beaufort Sea Environmental Program, completed in 1976, at a cost of $12 million was the single largest research program for this area. Engineering studies investigated the types of systems that could be used for exploration drilling.

By 1972 Esso began construction of artificial islands in the shallow waters (less than 20 metres deep) of the Beaufort Sea. Since then a total of 18 islands have been constructed in the area. A refinement of the artificial island, the caisson-retained island, reduced fill requirements. With both types of island year-round drilling is possible. Esso, Dome and Gulf have utilized the caisson-retained island. The use of artificial islands has also been applied at sites in the Mackenzie River at Norman Wells.

In deeper waters (from 20 - 60 metres) Dome Petroleum has, since 1976 used drillships for drilling wells. Support vessels are used to keep ice floes away from the drillship. The drilling season lasts about 110 days a year.

A new concept, the SSDC or semi-submersible drilling caisson has been used during the past year. The SSDC is a converted VLCC (Very Large Crude Carrier) oil tanker reinforced by steel and concrete. The vessel is ballasted down onto a submerged berm. The SSDC permits year-round operation.

The latest addition to the Beaufort drilling system is Gulf's Kulluk, a conical drilling unit suitable for drilling in deep waters. The Kulluk extends the drilling season in the Beaufort Sea.

The research undertaken has been by the individual operators and through joint efforts such as through the Arctic Petroleum Operators' Association (APOA) and the Canadian Offshore Oil Spill Research Association (COOSRA). The two organizations alone have spent about $60 million on research since 1970.

Since the early 1970s the hydrocarbon potential in the Territories has become better known. The Territories account for about 58% of Canada's maximum estimated undiscovered oil potential. Beaufort Sea oil and gas is still in the exploration/delineation phase. The results of the Beaufort EIS hearings now underway are expected to determine the scale and pace of development of the resources during production and the means of transportation to market.

Future Developments

In looking ahead to the future of the Canadian Arctic, science and technology and resource development will be expected to expand its role in two key areas:

1. In providing the basis for decision-making and,
2. In meeting northerners' aspirations.

Scientific knowledge provided through data gathering, analysis and interpretation and synthesized into environmental impact assessments is the principal means used by government, industry and northerners in directing the course of resource development. At some point judgements or decisions are made on the basis of this information. The effectiveness of the decisions made depends on the certainty and quality of the information provided.

Progressively, the decisions are being made less on an ad hoc basis and more in a defined, yet flexible, policy framework. Stated simply, the federal policy at DIAND is one of balanced development. At the territorial (NWT) level, resource projects are supported if a net benefit to the north is realized.

Science, technology and resource development will also expand its role in meeting the aspirations of northerners. These have been stated to include:

- participation in development,
- education,
- preservation of northern cultures,
- enhancement of the quality of life,
- energy self-sufficiency and,
- and economic development.

The question remains, how can this be achieved? and what contribution can science and technology make?

Oil companies meet some of these objectives by consultation, providing training, jobs, making northern purchases and through community development support.

Additional, broader-based approaches are necessary.

As scientific/technical knowledge and skills are crucial to making well-founded decisions in non-renewable and renewable resource management, research and analyses conducted by southerners can progressively be undertaken by northerners. The concept of a Northern Research Institute discussed at this conference, or a similar organization, deserves special attention as a focussing mechanism to achieve the dual goals of having a sound basis for decision-making and in meeting Northerners' aspirations.

A scientific centre could have a principal objective of encouraging the growth of a resident northern scientific/technical community and better informed populace by providing the following eight functions:

1. Access to information. Provision of library materials and information provided in an understandable form - such as the objective of the AAAS magazine Science 83 which is "to bridge the distance between science and citizen."

2. Training and participation in research activities. A good case in point is a study undertaken by the Arctic Institute of North America where native northerners assist and are taught research skills in the course of the project. This will enhance their ability to evaluate changes in their communities. The subject of the study is, by the way, on training. The Arctic Institute has also provided a summer course for Whitehorse students interested in learning of science and research skills.

3. For evaluating resource projects.

4. Identification of research requirements relevant at the local level. A case in point is the Baffin Region Inuit Association's Wildlife harvesting study. Hunters record their own catches for analysis.

5. For communications and consultation. A centre of information exchange for industry and government with northerners or local people on science. Seminars, lectures, discussions, and meetings could be held.

6. For contract research. Government and industry requiring studies could find them through a northern organization which could then conduct the work.

7. Sponsoring students for further education.

8. For training southerners in northern ways.

It should be pointed out that the Science Advisory Board of the Northwest Territories has been active in many of these types of activities.

The University of the North concept once discussed is perhaps on too large a scale at this time to be established. Rather, a pilot or demonstration project merits serious consideration.

In addition to meeting the aspirations of northerners, such an approach would ease the serious need for scientists knowledgeable of the north as expressed by Dr. Collin at the plenary session.

Achieving the aims associated with sound resource management and decision-making will require a partnership between northerners and southerners which provides opportunities for both.

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PART TWO

OPERATING IN THE ARCTIC

The oil and gas exploration companies working in Canada's Arctic have had to develop a variety of new and previously untried systems in order to conduct their drilling programmes. Operating in relatively shallow water, Esso has employed a series of artificial islands as drilling platforms. Gulf, working in deeper waters, has constructed a drilling fleet that can service one floating platform and one moveable, bottom founded steel drilling structure. These two systems are described in Section One, as are Dome's concepts for future production systems.

Section Two includes three papers on ice-breakers, critical support vessels for any type of industrial activity in ice-infested waters. The design characteristics of Gulf/Beaudril's four ice-breakers are described in the first article. Novel design features incorporated in the Canmar Kigoriak are discussed in the second paper, and the special challenges posed by the shallow draft requirements of ice-breakers deployed off the Alaskan Beaufort coast are reviewed in the final paper in the section.

Finally, one cannot operate in the Arctic without ready access to up-to-the-minute data on ice conditions and weather patterns. More generally, mounting an exploration programme requires information on an extensive range of environmental variables. Grittner, Karish and Stewart describe the ice surveillance programme developed for the North Aleutian Continental Offshore Stratigraphic Test Well Number 1, spudded in September, 1982 and completed in January, 1983. McNutt and her colleagues provide an overview of a detailed study conducted in the Bering Sea, documenting air-sea-ice interaction in a marginal ice zone, and involving data collection from ships, aircraft and satellites. Montgomery describes the Navy Oceanographic Data Distribution System which is used by offshore operators requiring marine weather and oceanographic information. The last paper in the section outlines the Canadian Arctic Data Compilation and Appraisal Programme.

SECTION ONE

OPERATING SYSTEMS

ESSO RESOURCES' BEAUFORT SEA EXPLORATION ISLAND CONSTRUCTION PROGRAM

by

R.D. PAWLUK and C.V. MANCINI

Esso Resources Canada Limited

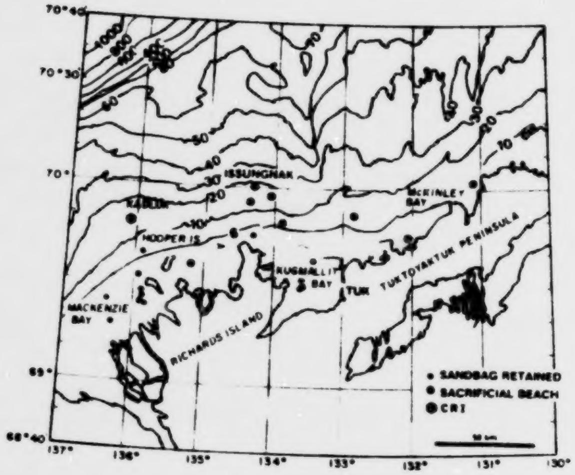
ABSTRACT

Hydrocarbon exploration in the shallow waters of the Canadian Beaufort Sea has relied upon the use of artificial islands as drilling platforms since 1973. Designed to withstand ice forces, artificial islands enable offshore drilling to continue throughout the long winter period. Esso Resources Canada Limited has constructed 18 artificial islands to date. The sandbag retained island has been used effectively in water depths up to 7 m. In deeper water where sufficient borrow material is locally available for dredging, the sacrificial beach islands have proven to be a cost effective construction technique. The largest sacrificial beach island constructed to date, Issungnak, is located in 20 m of water and required 4.9 million cubic metres of sand to complete.

The Caisson Retained Island concept was developed to allow exploration drilling to move to areas where local construction material was not available. In 1983, Esso Resources deployed its Caisson Retained Island system for the first time. This unique concept features eight steel caissons, each weighing 1500 tonnes, connected to form an octagonal ring held together by pre-stressing bands of steel wire cable. This system, which is an application of new technology, is allowing hydrocarbon exploration activity to effectively proceed in Esso's Beaufort Sea acreage.

1. INTRODUCTION

The sedimentary basin of the Beaufort Sea - Mackenzie Delta Region of Canada has all the attributes of a major hydrocarbon producing area. Since the early 1960s the oil industry has obtained 100,000 kilometres of seismic data, both onshore and offshore, which has led to the discovery of many potential hydrocarbon-bearing structures. Esso Resources Canada has played a significant role in the Beaufort Sea oil play since acquiring its acreage in 1964. Esso currently holds 6 million acres in the Beaufort Sea - Mackenzie Delta Region and about 60% of the holdings are in the offshore with an average water depth of 20 m. Since 1962, the oil industry has drilled 187 wells in the Beaufort Area and Esso has drilled or participated in 81 of these, including 18 offshore wells. (Figure 1 - Location Plan).


70°40
70°30
70°
69°
68°40
137°
136°
135°
134°
133°
132°
131°
130°
1000
500
100
60
50
40
30
20
10
ISSUNGNAK
KADLUK
HOOPER IS
MCKINLEY BAY
KUGMALLIT BAY
TUK
TUKTOYAKTUK PENINSULA
MACKENZIE BAY
RICHARDS ISLAND
• SANDBAG RETAINED
● SACRIFICIAL BEACH
● CRI
50 km

LOCATION PLAN

Figure 1

The Beaufort Exploration Program continues to expand and in 1982 took on a new direction for Esso with the signing of Exploration Agreements with the Canadian Government which include drilling commitments until 1986. This led to a major Farmout Agreement in 1982 for Esso and nine other Canadian companies to drill seven wells in the offshore and six onshore over five years.

This paper reviews Esso's history of constructing exploration islands in the Beaufort Sea, the environmental conditions of the Arctic, and the development and construction of Esso's caisson retained island which will see its first operation in 1983.

2. BEAUFORT SEA ENVIRONMENT

In the Beaufort Sea, the choice of exploration drilling systems is limited by the environmental conditions, ice conditions in particular, and by economics. In the shallow waters of near-shore locations, islands can be built most effectively and economically during the winter or in the summer. Once the island is in place the drilling season is relatively insensitive to weather. Where granular material for island construction is locally available, as in areas of the eastern Beaufort, dredged islands have proven to be most economical in water depths less than 20 m. Within these areas, sand, overlain by less than 5 to 10 m of clay, is present to a considerable depth. In the west, thick surficial deposits of soft silts and clays are present over a significant area. Caisson islands provide an economic alternative by significantly reducing the required fill volume when compared to conventional islands. In waters deeper than 30 - 40 m exploration drilling must be carried out with floating drilling systems such as drillships. Although drillships have a limited season, typically 110 days, building temporary exploration islands in these deeper waters is not economically attractive.

The design criteria for temporary exploration islands is primarily influenced by the environmental conditions and includes resistance to ice forces, protection against summer wave erosion, geotechnical stability of the island fill and of the seabed foundation, and availability and quality of granular fill material.

Ice plays a major role in design and construction plans. The Arctic Ocean is completely ice covered for almost nine months of the year. In an average year, breakup will begin in June and will be complete by mid July near shore. Freeze-up usually occurs about mid October. Island construction with marine equipment is limited to the open water season which generally extends from mid July to mid October.

The Beaufort Sea is characterized by three principal ice zones; the landfast, transition, and polar pack zones. Landfast ice is anchored to the shoreline or to the sea bottom and is relatively stationary with movement in the order of metres per day. This ice grows out from the shore to about the 20 m water depth by mid February, reaching a maximum thickness of about 2 m. The polar pack consists of multiyear ice 3 to 4 m thick with old pressure ridges which may reach 50 m in thickness. The polar pack ice drifts in a clockwise direction under the influence of winds, gravity, and ocean currents, and has a peripheral movement of 3 km per day. The transition zone between the moving polar pack and the stationary landfast ice varies in width from year to year due to shifts of the polar pack. The transition zone consists of first-year or seasonal ice which forms in early October and lasts until July. This zone is characterized by large ridges and open leads and in some years extends into Esso's acreage.

The impact of operations on the biological environment is of primary concern. In spring, white whales and bowhead whales migrate to the Beaufort from wintering areas in the Bering Sea by way of offshore leads. Each summer, thousands of white whales migrate to the estuary of the

Mackenzie River. Whale monitoring studies have been conducted since the first island construction to prevent any adverse effects on whales and whale hunting by the natives. During the winter months, polar bear and Arctic fox inhabit the nearshore Beaufort Sea. In order to protect personnel, as well as wildlife, strict procedures are established to ensure safe operating conditions.

Exploration activity in the remote Arctic environment also requires extensive facilities to support drilling and construction operations year-round. Esso's Tuk Base Camp, located in Tuktoyaktuk, serves as the center of the support infrastructure for the Beaufort Operations. It features warehousing, storage, and shop facilities, as well as a modern 120-man camp. Tuk Base handles all equipment and fuel transported by barges along the Mackenzie River during the summer from supply points in the south.

3. HISTORY OF ESSO'S EXPLORATION ISLAND CONSTRUCTION PROGRAM

The first offshore well in the Beaufort Sea was drilled in the winter of 1973-74 by Esso from the artificial island Immerk B-48. The island was constructed at a fairly sheltered location in the offshore delta in a water depth of 3 m. The first winter demonstrated that the island could withstand the winter ice. In retrospect, Immerk was relatively inexpensive and simple to construct but, at the time, it represented one of the first structures exposed to Beaufort Sea ice conditions.

To date, industry has built and drilled from 22 artificial islands in the Canadian Beaufort Sea. Most have been built in the summer by dredging sand from the seabed but some have been constructed in winter by trucking gravel over the ice. As working knowledge of the Arctic has improved, construction efficiency has been gradually improved as islands are planned for greater water depths.

The principal types of islands constructed by Esso to date include the sandbag retained and the sacrificial beach types. (Table 1).

TABLE 1

HISTORY OF ISLAND CONSTRUCTION

ISLAND LOCATION	YEAR BUILT	WATER DEPTH METRES	ISLAND TYPE
Immerk	1972-73	3	Sacrificial Beach
Adgo F-28	1973	2	Sandbag
Pullen E-17	1974	2	Sandbag/Trucked
Netserk B-44	1974	5	Sandbag
Adgo P-25	1974	2	Sandbag
Netserk N. F-40	1975	7	Sandbag
Adgo C-15	1975	2	Sandbag/Trucked
Ikattok J-17	1975	2	Sandbag
Sarpik B-35	1976	4	Sandbag/Trucked
Kugmallit H-59	1976	5	Sandbag
Arnak L-30	1976	9	Sacrificial Beach
Kannerk G-42	1976	8	Sacrificial Beach
Adgo J-27	1976	2	Sandbag
Isserk E-27	1977	13	Sacrificial Beach
Issungnak O-61	1978-79	20	Sacrificial Beach
Alerk P-23	1980	12	Sacrificial Beach
West Atkinson	1981	7	Sacrificial Beach
Itiyok I-27	1981-82	14	Sacrificial Beach
Kadluk O-07	1982-83	13.6	Caisson Retained

The sandbag retained island uses a berm of sandbags to minimize the volume of fill required in areas where sand borrow is scarce. It has been used effectively in relatively shallow water up to 7 m depth. The sacrificial beach island is characterized by long gradual beaches and underwater slopes of about 1:12. The beaches force storm waves to break and thereby dissipate their energy before reaching the island proper. In winter, the sacrificial beach promotes ice sheet failure which develops into a protective rubble field around the island. Secondary slope protection is provided by sandbags and filtercloth on the beaches and around the drilling surface.

Issungnak is the largest sacrificial beach island constructed to date and required two seasons to complete. Located in 20 m water depth, the island required 4 million cubic metres of hydraulic fill material. Following a successful drilling program in the winter of 1979, further construction in 1980 to permit the drilling of a directional well increased the total island volume to 4.9 million cubic metres.

A stationary suction dredge is the most effective method of constructing a sacrificial beach island such as Issungnak. Material is dredged from a borrow pit which has been delineated for aerial extent, material type, and material depth. The material is then conveyed to the island site through a floating pipeline. The feasibility of constructing a sacrificial beach island with a stationary suction dredge is dependent upon the availability, distribution, and quality of borrow material in the immediate area.

By dredging sand from the seabed and delivering it through a floating pipeline to the island the Beaver Mackenzie dredge can achieve production rates of up to 3,000 cubic metres per hour. The material is pumped through an 800 mm diameter floating pipeline, 800 m in length, to a discharge pontoon anchored on the island site. Depending upon water depth, placement of material in this manner approaches 80% effectiveness with losses attributed generally to removal of fines.

As the dredged sand begins to break the water surface, construction equipment is put ashore to extend the beaches using shore pipelines connected to the discharge pontoon which is now grounded. As the beaches are developed, a berm 110 m in diameter is constructed to an elevation of 5 m above sea level to provide the drilling surface. The beaches typically extend 50 m from the edge of the berm and in most cases are protected to reduce the effects of wave erosion by using sandbags overlaying filtercloth.

Shortly before freeze-up, a conventional land rig is barged to the island and drilling commences. As ice moves into the vicinity of the island during the freeze-up period, the shallow underwater slopes promote grounding of the ice to form a rubble field. The ice rubble provides additional shear resistance to withstand the lateral forces from the surrounding ice sheet. Drilling can then continue uninterrupted throughout the winter until the open water period. About 250 days are available during this period and if promising geologic zones are drilled, a full evaluation with logs, cores, and tests is usually possible in the same season. Delineation wells, if required, are economical since directional wells can be drilled from the same structure provided that the beaches are rebuilt to withstand another season of exposure to waves.

Once drilling is completed the rig and equipment are removed and all debris and man-made slope protection materials are cleaned up to permit natural erosion of the island. Following island abandonment, bathymetric surveys are conducted over successive years to monitor erosion rates. This data is useful for design of future exploration and production islands.

4. SOURCES OF GRANULAR FILL

Figure 2 illustrates the distribution of areas considered to be potential borrow sources for island construction. An estimated 230 billion cubic metres of sand is available as dredgeable material from the areas of known good borrow. Within these areas, sand outcrops at the seabed and is present to a considerable depth. The sand can also be overlain by patchy to continuous clay which is usually less than 5 m thick. In the west, thick surficial deposits of soft silts and clays are present over a significant area.

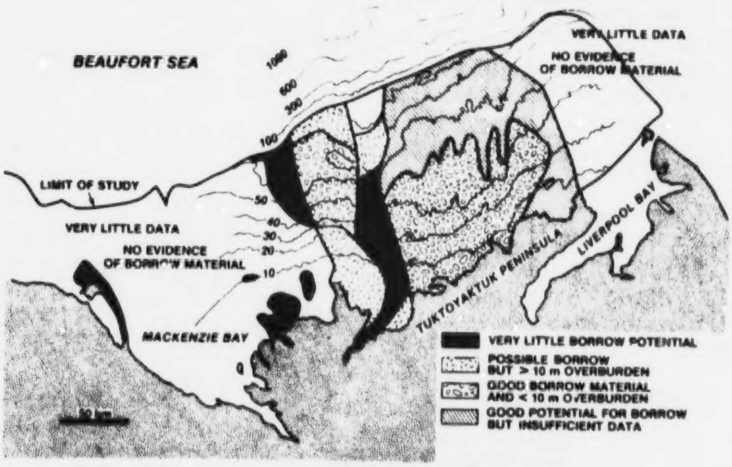

BEAUFORT SEA
1000
600
300
100
50
40
30
20
10
0
VERY LITTLE DATA
NO EVIDENCE OF BORROW MATERIAL
LIMIT OF STUDY
VERY LITTLE DATA
NO EVIDENCE OF BORROW MATERIAL
MACKENZIE BAY
TUKTOYAKTUK PENINSULA
LIVERPOOL BAY
VERY LITTLE BORROW POTENTIAL
POSSIBLE BORROW BUT > 10 m OVERBURDEN
GOOD BORROW MATERIAL AND < 10 m OVERBURDEN
GOOD POTENTIAL FOR BORROW BUT INSUFFICIENT DATA
50 km

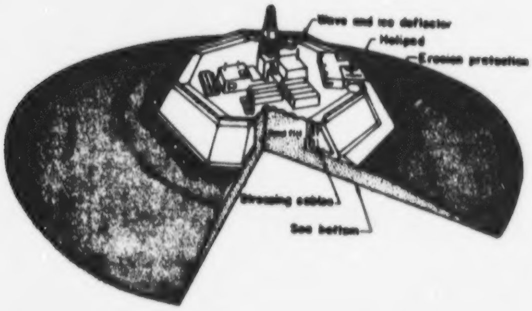
FIGURE 2 – **BORROW PROSPECTS OF THE BEAUFORT - MACKENZIE REGION**

Esso's offshore exploration leases extend from the western edge of Mackenzie Bay to the eastern tip of Tuktoyaktuk Peninsula and from the shoreline out to about the 20 m water depth contour. Issungnak would be typical of islands that would have to be built in the deeper waters of the Western Beaufort acreage. In place cost per cubic metre of dredged material at Issungnak was about $12. This includes not only dredge costs but also support equipment and transportation facilities. Cost per cubic metre of material increases substantially once it is hauled from remote borrow sites. Cost per cubic metre of material hauled to an island site in the Western Beaufort from a borrow site 120 km to the east is about $45. Construction of a sacrificial beach island at this rate would make future exploration work uneconomic in areas of poor borrow potential.

5. CAISSON RETAINED ISLAND DEVELOPMENT AND DESIGN

In the mid 70s, anticipating exploration activity in the Western Beaufort acreage, Esso developed the design of a steel caisson retained island (CRI) recognizing that this system could substantially reduce island fill requirements. With the signing of the Exploration Agreements in 1982, Esso made the decision to use the CRI to meet the requirements of the Exploration Program.

The CRI design, shown in Figure 3 consists of eight caissons connected to form an octagonal ring. Each caisson measures 43 m long by 12.2 m high by 13.1 m wide and weighs 1500 tonnes. The total ring weighs 12,380 tonnes and the outside diameter measures 117 m. The caissons are held together by two pre-stressing bands of steel wire cable. Each band uses eight 75 mm diameter cables with a breaking strength of 400 tonnes. The total length of 75 mm diameter cable measures 5 km. Pre-stressing of the cables is achieved by a hydraulic jacking system consisting of thirty-two 800 tonne capacity jacks. Design pre-stress equivalent to the restraining force required for stability under active earth pressure was chosen based on results of geotechnical analysis.



CAISSON RETAINED ISLAND

Figure 3

The main features of the caisson include:

- a draft of 2.7 m for shallow water transportation and assembly
- the outer face of the caissons is designed with a slope of 60° to the horizontal to minimize ice loading on the structure
- it is reusable, with a life-expectancy for at least three drilling locations
- the system is deployed as a single unit.

The complete ring is ballasted down onto a sand berm, levelled to a tolerance of ±30 cm. Only water ballast is used to simplify and expedite the deballasting and relocation procedures. The centre core of the ring is filled with sand to provide the working area and for stability against ice loads. Vertical joints provide articulation during the consolidation period of the island base and the core fill. The caisson ring has a setdown depth of -9 m providing it with a freeboard of 3 m. Angled wave deflectors extend an additional 4.5 m above the deck to +7.5 m to protect the island from summer waves and to minimize over-topping. At the ice impact zones, high-ductility, high-tensile, normalized steel is used. The CRI is instrumented with structural, geotechnical, and ice sensors to monitor the forces acting on the structure. Depending upon the water depth, the CRI design reduces the volume of fill material by up to 80% of that required for a sacrificial beach island. This reduction is primarily the result of eliminating the broad base required to develop the wide sacrificial beach in the wave zone. The CRI concept thus makes more effective use of the available granular resources as well as the dredging equipment.

The CRI design incorporates the data of many years of ice research conducted in the Beaufort Sea through field investigation as well as through analytical experiments and ice basin tests. Design ice forces were verified in the ice basin at Esso's Research facilities in Calgary. During the summer, wave studies were conducted at the basin to verify calculations for wave overtopping and berm erosion. The wave basin incorporates a computer-controlled random wave generator and is capable of simulating 6.5 m waves on a 1:25 scale model of the CRI.

The caissons were fabricated over a five-month period in 1982 at Hitachi's Sakai yard near Osaka, Japan. The low temperature steel used in fabrication was purchased in Canada and shipped to Japan. Although fabricated in Japan, the total Canadian content for the 55 M$ caisson project exceeded 35%.

Following extensive testing of all systems, the caissons were loaded onto two transport barges and left Japan at the end of July, arriving at Esso's base in Tuktoyaktuk four weeks later. The caisson ring was assembled and tested in Tuktoyaktuk Harbour upon arrival in late August, 1983. Following the Tuk Harbour trials, the caissons were anchored in the harbour and winterized to await deployment at the Kadluk drilling location in the summer of 1983. (Figure 4).

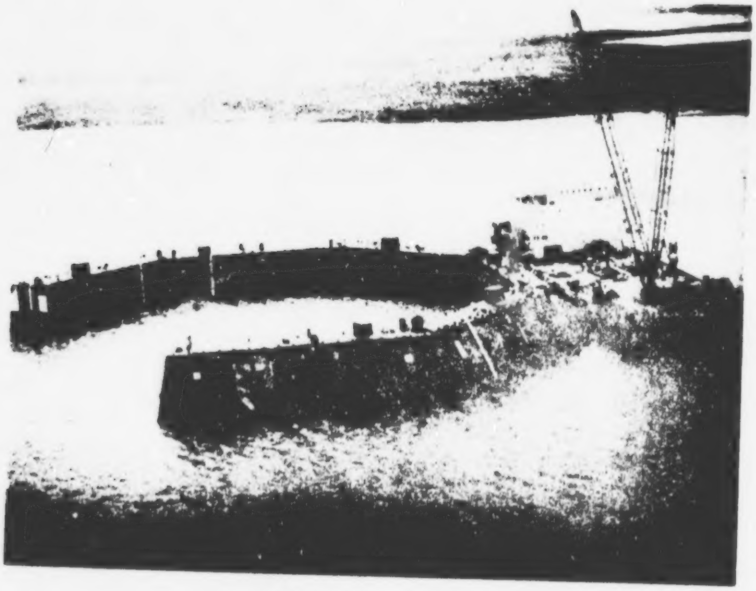


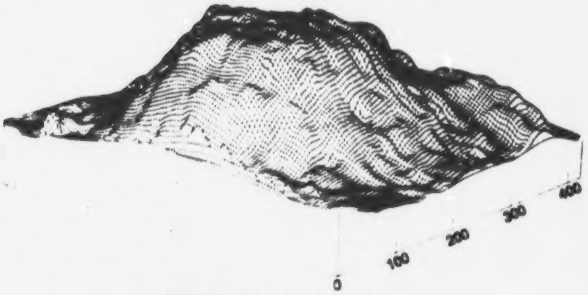
Fig. 4—Caissons assembly in Tuktoyaktuk

6. CAISSON RETAINED ISLAND CONSTRUCTION

Construction of the CRI berm began at Kadluk in 13.6 m water depth during early August 1982. Sand fill was hauled to the island site from a borrow area situated 120 km to the east. A trailer suction hopper dredge was used to load and haul good quality material to the island. The dredge loads its hopper by dragging two suction heads across the sea floor. At the island, the material is dumped through a series of bottom-discharge valves. The W. D. Gateway, a 6,000 m^3 capacity dredge, was used for the Kadluk berm construction. The dredge has a sailing speed of 16 knots fully loaded. The loading and dumping operations each take about one hour to complete. At two round-trips per day, daily production was about 11,600 m^3.

The berm required 450,000 m^3 of fill and an additional 100,000 m^3 was dumped in a stockpile adjacent to the berm to provide material to fill the core of the caisson ring. A computer-produced perspective of the berm as constructed in the summer of 1982 is shown in Figure 5. The berm was levelled at the start of the 1983 season, prior to caisson setdown.

KADLUK O - 07



OCTOBER 7, 1982 SURVEY
VIEW FROM THE SOUTHEAST
VERTICAL EXAGGERATION 20X

FIGURE 5 KADLUK BERM PERSPECTIVE VIEW

In early August 1983, the caisson ring was towed to the Kadluk location using two 6,500 HP tugs. Once on location, mooring lines were connected to four preset anchors and the caisson ring was positioned over the berm by adjusting the four line-lengths to the spot indicated by a radar positioning system. Once over the precise location, ballast water was admitted into the ballast tanks by operating valves from the deck of the individual caissons. The ballast tanks were then pumped full to increase the weight on the bottom to minimize the possibility of lateral movement.

Once the caisson ring was ballasted down onto the berm, the infill operation began by dredging sand from the stockpile adjacent to the berm. The 6,000 m^3 capacity trailer suction hopper dredge Cornelis Zanen worked with the Gateway to fill the interior of the caisson ring. The dredges delivered sand to the caisson through floating pipelines. The pipelines from the dredges were connected to a discharge pipe located on the crane barge, Arctic Kamotik, which was anchored alongside the caisson. A discharge pipe gantry permitted placement of material over the caisson wall and into the core of the caisson ring. The infill operation was completed within 10 days of caisson setdown. During this period three days were required to place over 30,000 m^3 of gravel toe protection along the perimeter of the caisson to prevent scour of the berm. The rig move began in late August and within three weeks the caisson rig and all drilling equipment and materials were on location and ready to spud the Kadluk well.

The success and efficiency of the entire CRI operation was good news to Esso and its Canadian partners who are looking forward to an exciting exploration program employing this new system. It will allow exploration to continue on a number of high-potential targets in Esso's Western Beaufort acreage.

7. BEAUFORT SEA DRILLING SYSTEMS

Industry has responded to the technical challenges facing hydrocarbon exploration in the Beaufort by developing other unique exploration systems. Dome and Gulf have deployed a concrete gravity structure at the Tarsiut location. This system was first to demonstrate the feasibility of a caisson system for drilling in the Beaufort Sea environment. Following their experience at Tarsiut, Dome developed the Single Steel Drilling Caisson (SSDC) which makes use of a converted decommissioned tanker. It has also proved successful in drilling at Uviluk. Gulf's response to explore in its acreage, which is in the 30 m - 40 m water depth range, is the Mobile Arctic Caisson (MAC). The MAC, which features an integrated steel deck to support the drilling equipment, is expected to be completed for drilling next year. And, currently, Gulf is operating the Conical Drilling Unit (CDU) which was designed to extend the drilling season of conventional drillships.

The Beaufort oil discoveries announced over the past few years have encouraged the continuing activity in hydrocarbon exploration. Esso Resources believes that there are sufficient reserves to supply a substantial volume of crude oil to meet the Canadian demand in the 1990s and in turn help to ensure our national goal of energy self-sufficiency.

The continued development of economic and technically-feasible concepts for hydrocarbon exploration in the Arctic will be a major factor in realizing the Beaufort as an oil-producing region of great significance to Canada.

8. ACKNOWLEDGEMENT

The authors wish to express their appreciation to Esso Resources Canada Limited for permission to publish this paper.

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BEAUFORT SEA DRILLING SYSTEM

by

J.K.S. LOH

Manager
Beaufort Sea Drilling System
Gulf Canada Resources Inc.

1. INTRODUCTION

Thank you Mr. Chairman, Good Afternoon ladies and gentlemen.

First of all, I would like to explain it is not my intention to give you a technical paper. This is a brief 8-minute summary of Gulf Canada Resources undertaking in the Arctic. I hope to stimulate enough interest to generate some questions and discussions into the subject of new drilling technology for the harsh environment that we find ourselves operating in. We also have published numbers of technical papers in the past that deal with more detailed technical areas. At the end of the sessions, if you could give me your names and addresses, I can send you the reprints of these papers.

For my short remark, let me begin with a brief reference to a Gulf Canada Resources News Release dated June 22, 1981. The opening paragraph read as follows:

"Gulf Canada Resources will spend $674 million to build and operate a Beaufort Sea Drilling System. In the summer of 1983 the system will begin an exploration program on Beaufort Sea acreage holdings operated by Gulf Canada Resources."

You noticed the statement did not use the words "plan to begin", or "expects to begin". It reads "the system will begin an exploration program in 1983." Considering the magnitude of the project, I think it was really gutsy of our Public Affairs Department to commit me, and Gulf's entire Beaufort Sea Drilling System Division to this 26-month obstacle race.

However, thanks to a superb, dedicated staff in my division, and outstanding workmanship at Mitsui Engineering and Shipbuilding at Tamano, the Conical Drilling Unit, Kulluk, the first piece of equipment was launched on schedule under budget, on January 31st of this year. The Kulluk was subsequently turned over to Beaudril on April 1st. In the summer it was towed across the Pacific, around Point Barrow and into the Canadian Beaufort Sea where it spudded the Pitsiulak well on August 22.

The second drilling unit, the mobile arctic caisson, was launched on schedule on June 22, and top-side facilities now are being put in place. She will follow Kulluk's route across the Pacific next summer as scheduled. The planned delivery date is April 16th, of 1986.

Gulf had little choice, of course, in setting the two-year construction schedule. The National Energy Program was six months in place; Gulf was operator of 637,000 hectares of Beaufort Sea Permits -- since increased to over a million hectares. Under NEP we would be required to negotiate and conclude an exploration agreement within what amounted to a 12-month period, and there were indications of stiffer drilling commitments. The problem we faced was two-fold: First, that much of the Gulf-operated acreage lies in water depths too great for Artificial Islands; and second that conventional drillships would not be available to meet accelerated industry programs.

The answer was a new drilling system. And if we were to design, build and operate a new system, why not advance Beaufort Sea technology with equipment that would extend the drilling season, as well as give us the capability of drilling in a wide range of water depths. An executive board approval of $674 million in capital expenditure on June 16, 1981 resulted in the creation of a fully dedicated Beaufort Sea Drilling System Division. The Division was given the responsibility of conceptual design through design, construction and preoperating planning of a second generation drilling system.

The total Beaufort Sea Drilling System comprises of two new drilling units, four support vessels, and a large new administrative base at Tuktoyaktuk. In addition, there are several tugs, barges and a tanker for storage of 94,000 tonnes of diesel fuel. The system is owned and operated by Beaudril Limited, the offshore drilling subsidiary of Gulf Canada Resources. Mr. Don Park, who is no newcomer to Arctic drilling, recently was appointed President of Beaudril.

2. ICE-BREAKERS AND SUPPLY VESSELS

The four support vessels I referred to a moment ago, comprise two ice-breakers, Terry Fox and Kalvik and two ice-breaking supply vessels. These vessels were discussed earlier in a separate paper by Dr. Robin Browne, of Gulf Canada Resources. Therefore I'll mention only a few significant facts:

First, all the vessels are Arctic Class IV;

Second, although by design the ice-breakers and supply vessels have primary functions, all are capable of ice management, anchoring handling, towing and supply services;

And third, the ice-breakers have 24,000 installed horsepower, and are the most powerful, privately-owned ice-breakers in the world.

Figure 1 shows the supply vessel Ikaluk with Kulluk in tow near Prudhoe Bay in August, en route to the Canadian Beaufort. The ice-breaker, Kalvik is barely visible in the fog on the horizon. During this portion of the tow, Kalvik successfully broke through 3- and 4 1/2-metre first-year ice and also broke through some significant ridges during the tow. She performed well -- beyond expectation. We currently have three vessels in the Beaufort, with the fourth en route arriving within the next few days.

Figure 2 is an artist's drawing of Molikpaq, the mobile arctic caisson, a massive annular caisson structure. Designed for use in locations of 14-to-40 metre water depth. It has the capability to drill to a total depth in excess of 6,000 metres. It will sit on a prepared foundation when drilling. This eight-sided, hollow steel structure will weigh approximately 30,000 tonnes, has a deck size of 74 metres square, and its base will cover the area of nearly two football fields. It will accommodate 100 people. Unlike many previous caissons, Molikpaq features one-piece construction. The drilling rig, accommodations, and auxiliary equipment are permanently fixed on the structure's deck, eliminating transportation and reconstruction costs when the unit is moved. The modular buildings on the deck are permanent and heated, providing protection in the harsh arctic environment.

Figure 3 is the hull of Molikpaq during construction, and perhaps it better shows her size and shape. She has been designed to resist the greatest ice forces anticipated, and therefore has the capability of year-round drilling. Because of its height, the base of the unit will be below the turbulent zone. Consequently, wave erosion in summer will not be a problem and maintenance costs will be greatly reduced.

Molikpaq was launched in June, prior to top-side installations as shown in Figure 4. On location moves she will be towed by ice-breakers and supply vessels. Once in position, the ballast system will allow descent onto the foundation. The caisson core will then be filled with sand supplied by dredges and barges. The sand is dewatered by means of pumps, and kept from freezing by waste heat from the drilling operation.

The hollow core of Molikpaq will hold 115,000 cubic metres of dredged seabed material at its deepest setting depth. Because this is a fraction of the fill required to construct a sacrificial beach island, there will be a considerable reduction in time and construction costs. Once the core has been filled, Molikpaq will be able to withstand ice forces up to 100,000 tonnes without being pushed off its subsea foundation. Therefore an effective year-round operation is possible.

Slide 5 shows the Conical Drilling Unit, Kulluk, following launching last January. She is a floating drilling unit capable of drilling to 6,100 metres. The unit weights 17,500 tonnes, has a deck size of 81 metres in diameter, and accommodates 108 people.

Kulluk is designed to operate in water depths of 25 - 55 metres. This area is subject to complete ice cover, and Kulluk is designed to withstand the forces associated with moving ice during early winter and break-up.

This capability is provided by Kulluk's specially designed ice-deflecting hull (Figure 6). The main hull slopes inward at an angle of 31 degrees, and deflects the ice downward. This results in a horizontal force of only 20 to 25 percent of that produced by an upward-deflecting hull. The hull is constructed from 24 steel sections which are used as ballasting chambers, and is rated for Class IV ice conditions.

Slide 7 during drilling operations shows the Kulluk being held in position by twelve anchors attached to 89 millimetre radially deployed mooring lines which are capable of being acoustically released from the anchors at any time, if necessary. Transducers mounted on the hull and on the sea floor are used to monitor the position of the vessel over the well location.

Because of its ability to deflect oncoming ice, Kulluk is expected to significantly extend the three to four-month season for a conventional drillship (Figure 8). This extension will enable the vessel to drill, test, and complete most wells in a single year.

This is Kulluk Drilling Pitsiulak A-05 in the Beaufort Sea. The unit will be towed to a sheltered location for the remaining winter months.

MOVING TOWARDS ARCTIC PRODUCTION

by

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ABSTRACT

The encouraging results of exploration in the Beaufort Sea indicate that sufficient reserves will be found within the next few years to justify the expenditure necessary for production.

This paper discusses what has been accomplished to date and how experience gained during exploration can be used to develop plans for production. The paper is primarily concerned with production platforms (sub-structures) and the problems associated with using them to support future production facilities.

There are a number of engineering solutions available to operators in the Arctic for support structures. These range from concrete platforms to artificial islands. The solutions, coupled with methods of transportation, early production systems, reservoir development, fabrication and installation, create an extensive matrix of development options. Some of the basic classes of structures are discussed with the intent of highlighting the primary requirements of a sub-structure and reviewing the most appropriate locations for the classes of structures considered under a certain set of circumstances.

1. INTRODUCTION

The purpose of this paper is to try to put some of the major requirements of production development, with respect to the sub-structure, into perspective. The term 'sub-structure' is a general term used to describe the system which supports the production facilities. Numerous sub-structure concepts have been prepared throughout the last few years but little has been stated about the exact requirements of these structures. It is therefore difficult to assess whether a concept is satisfactory or not.

During 1983 the Frontier Divisin of Dome Petroleum Limited has conducted a number of studies to more clearly define the requirements of a production facility. In conjunction with these studies work has been carried out to group similar concepts into a small number of classes to determine the characteristics of each class. These characteristics are then compared to known requirements in order to assess which class of structure is most suitable to which circumstances. The work is complicated by the fact that the sub-structure is only part of an overall production scenario and also because the insitu behavior is only one aspect of design. Other aspects include the design process and the fabrication and installation activities. In order to make this paper less abstract, it has been necessary to make some simplifications. Nevertheless, the underlying trends are insensitive and hopefully are clearly stated.

Initially, an overview of conditions throughout the Beaufort is described, followed by a discussion of how these conditions, in conjunction with functional requirements, affect substructures. A set of basic requirements is then given which is followed by a review of different classes of structure which are most suited to certain locations and conditions.

2. OVERVIEW OF ENVIRONMENTAL AND FOUNDATION CONDITIONS IN THE CANADIAN BEAUFORT SEA

This section is intended to give an overview of the conditions which exist in the Canadian Beaufort Sea. This will provide a background to site specific conditions in order to make the review in Section 3 more understandable. The data given is not comprehensive, however, it is hoped that all the primary conditions which influence the design of an Arctic production platform are mentioned if not fully quantified.

2.1 Ice Conditions

Two major ice zones exist between the shore and the polar pack. These are the landfast zone and the transition zone. Future production from the Beaufort will be concentrated in these two zones.

The landfast zone extends from shore to approximately the 20 m water depth and the transition zone lies between the landfast zone and the polar pack. Large sections of ice within the landfast zone may move periodically but generally the landfast ice is stable first-year ice which does not move significantly during the winter months. The landfast ice is grounded locally at its outer edge due to ridging and it is also grounded at the shoreline. It is difficult for large multi-year ice features to be active in this zone during the winter but during the open water season present data indicates similar probabilities for the presence of multi-year ice in both zones. Ice within the transition zone tends to move continuously through the winter months and is primarily wind driven. The majority of the ice is first year, but multi-year features are often present, sometimes with extensive coverage.

The principal difference between exploration and production structures, in terms of design ice load exceedance, stems from the requirements of long term permanence and low risk levels that are forced on production structures.

The combination of the acceptance of less risk (because of the greater consequences) together with a thirty year design life means that rare and unusual loading events must be considered. As a result, first year ice loadings generallly become less significant, and the relatively rare, dynamic loading conditions of large multi-year ice floes or ice islands become increasingly important. The risk of an encounter with an extremely large feature during exploration is minimal, however under a long term permanence requirement an encounter with an ice island approximately 20 km in diameter travelling at 0.5 m/second and having an energy of some 300 giga joules has about a 1% chance of occurring.

As ice islands and multi-year floes can vary from about 5 m to 60 m in thickness both locally and throughout, it is reasonable to state that the maximum thickness of ice that can interact in a dynamic or quasi static mode with a production structure is potentially the lower of the following two parameters:

1. The upper bound thickness of 60 m.
2. A thickness equal to the ambient water depth.

As a direct consequence of the long term exposure factor, production structures in deep water have the potential for load interaction scenarios that are close to an order of magnitude greater than those of typical exploration design criteria.

Since production structures must be designed with such interactions in mind, and because these encounters will generally only occur in extensive open water (which allows high velocites to build up) we have the seemingly paradoxical situation that the short relatively ice free summer is one of the most threatening situations to production structures.

2.2 Foundation Conditions

It is difficult to generalize foundation conditions in the Beaufort and obviously specific parameters will have to be establisned for each intended production location. However, there is information available, primarily borehole data resulting from the search for borrow materials which is adequate to give at least an overview of the foundation conditions present. It appears that there are at least three major foundation conditions which predominate.

Area 1

Area 1 covers about fifty per cent of the development area between Herschel Island and Cape Dalhousie. In this area, sand outcrops and is present to a considerable depth. The sand can also be overlain by clay which is usually less than 5 m thick. The sands typically contain small amounts of fines and are compact to dense insitu. Some of the overlying clays are fine grained surficial deposits and tend to be soft and underconsolidated. These clays can easily be removed by dredging prior to placing a production structure

Area 2

Area 2 covers about twenty per cent of the development area. This area consists of a veneer of soft clays overlaying stiff to hard marine silt. Stiff overconsolidated clays frequently outcrop at the sea bed. The thickness of weak surficial deposits is variable but conditions suitable for production structure foundations are usually present within 5 to 10 m of the sea bed. It may be necessary to strip away the weaker surficial material prior to placement of a structure.

Area 3

Area 3 covers the remaining thirty per cent of the development area and consists of thick surficial deposits of soft silts and clays. The majority of these deposits are river sediments. This area generally presents foundation problems for which various solutions including sub-cutting, preloading, foundation drainage and replacement will be necessary to obtain adequate foundation conditions. Nevertheless it is known that in certain locations sand lenses are present within 10 to 15 m of the seabed which will provide an adequate foundation for gravity structures.

2.3 Seismicity

The Beaufort Sea is considered a seismically active zone and is generally classified as Zone 2 in the National Building Code. There are also portions of the development area classified as Zone 3. Generally, ground accelerations can be expected to increase towards the edge of the continental shelf. For the purposes of conceptual design, accelerations may be considered to vary between five per cent of gravity at the coastline, to fifteen per cent at the edge of the continental shelf. The primary concern in design is with liquifaction, also static slope failure of fill materials or foundations. Although there is no major concern regarding the use of borrow materials in the Beaufort for the construction of sand berms, continual quality control will be necessary during construction to ensure acceptable behavior during earthquake loading.

2.4 Water Depth

The majority of the area of the Beaufort Sea presently being explored is east of Mackenzie Bay. The sea bed in this area slopes very gradually from the shore to the edge of the Continental Shelf. The water depth varies from 0 to

70 m over a distance of approximately 80 miles. West of Mackenzie Bay the sea bed slopes towards the Continental Shelf much more rapidly, particularly around Herschel Island.

2.5 Open Water Conditions

The open water season generally lasts from mid July to mid October. Occasionally, the season extends into June or November. Records from Dome drillships indicate that the drilling season is 90 days with 15 days downtime recorded due to ice invasion and storms. The downtime is based on an average of the three worst years in six years.

Storms during the open water season are not severe compared to other offshore locations. The once in fifty year storm is estimated to be a 6 m significant sea state. However, it should be noted that sea states can be amplified locally by the introduction of an obstruction such as a production platform. Wave height amplification local to an installation can be about 1.5. One can generally expect one or two storms per year with a significant wave height of 3 m. These storms tend to occur during September and October. The associated storm surge offshore is negligible, however at certain nearshore locations local storm surges can be as high as three meters.

The transportation route into the Beaufort from the West is via the Bering Straits and past Point Barrow. The open water period at Point Barrow is a critical factor when considering the possibility of towing large equipment into the Beaufort. Studies to date have indicated that it is possible to navigate a 30 m deep course through this route 8 years out of 10. Normally vessels can be standing by near Wainwright as early as the first week in August and may remain there for a number of weeks before being cleared to move past Point Barrow sometime in September. Predicted arrival dates in the Canadian Beaufort, for vessels using 1968 to 1981 data, range from August 15 to October 9.

3.0 THE IMPACT OF SITE SPECIFIC CONDITIONS AND FUNCTIONAL REQUIREMENTS UPON PLATFORM CONCEPTS.

Engineering studies to date have produced a large number of arctic production concepts, some of which have been quite ill-concieved. Usually an unsatisfactory concept is a concept which is developed in isolation from the overall requirements of arctic production. However, up to this stage in development planning, it is understandable that many concepts have been proposed which do not meet the overall requirements of arctic production since it is only recently that a reasonable statement of concept requirements has become available.

The basic purposes of an arctic production platform are similar to those of structures at any other offshore location. The purposes are to support drilling and production facilities, to resist the environment, and to ensure that the structure can be designed, built and installed within an acceptable time frame, at an acceptable cost. The structure must also remain serviceable for a specific time without the necessity for major repair. In order to design a structure which will fulfill those purposes, it is first necessary to have a good understanding of the functional requirements, relating to the modes of transportation and the methods of construction, installation and production. Also, an understanding of how these requirements are affected by site specific conditions and the general environment is necessary. The functional requirements of course do not change but the solutions developed to meet these requirements differ according to site specific conditions. Therefore, at a specific site there may be only one or two concepts, out of the many available, which meet the design and commercial requirements.

During the following review of functional requirements and site conditions, certain assumptions have been made in order to make it more meaningful. Although some of the assumptions stated will change from project to project the approach taken is of general applicability.

3.1 The Impact of the Transportation System

The transportation system for production may be by either tanker or pipeline and in some instances may be a combination of both. The requirements of the system chosen can influence the class of offshore platform required. The tanker system requires mooring and loading facilities as well as suitable storage capacity at or near the production facilities.

Historically, tanker systems have been used in the initial phases of many developments because the system is less expensive to initiate than an offshore pipeline and can be operational in less time.

Pipeline systems have less impact on the structure and facilities than the tanker system. This is because there is no requirement for storage of crude or mooring facilities. Pipeline systems are more expensive than tanker systems and therefore require higher production rates to be economic.

Transportation by Pipeline

There are a number of problems unique to installing pipelines in the arctic environment. Particular to arctic regions are the problems of ice scour, the difficulty of repairing damaged pipelines during the winter, the problems associated with permafrost at the shore approaches and at some locations on the seabed, and the expense of installation due to the short open water season. Because of scour it is probable that most pipelines will have to be set in a trench which would be about 5 m deep. Ploughing trenches of this depth does not appear to be feasible, therefore specially adapted dredges will be required. Solutions for overcoming problems of settlement in permafrost at the shore approaches are available, and in general work can be carried out in this area through the winter, from the stable landfast ice. A major concern with pipelines is their repair, should they be damaged during the winter months. In many areas it is not possible to work from the ice because as the pipeline approaches the transition zone, or in fact if it is in the transition zone, the continually moving ice cannot provide stable support. Also, the floating landfast ice can fracture and move in an unpredictable fashion. Floating pipeline repair vessels may not be able to moor at the location where the pipeline is damaged and it is unlikely that they could even make the voyage through severe landfast ice conditions. These problems however do not influence the class of structure required but have more impact upon choice of transportation mode.

The major element of the pipeline system which has some influence on the production platform concept is the pipeline tie-in. There are two basic classes of platform which may be considered for pipeline tie-in and these are; an installation on a sand berm or an isolated gravity platform placed on the seabed. Seabed supported gravity platforms are little influenced by platform tie-in as standard techniques in other offshore locations can be adopted. All that is required is that sufficient risers are installed during fabrication and that a sub-sea tie-in is completed when the pipelines are brought alongside. Concepts which require a sand berm create more of a problem regarding pipeline tie-in. This is because the risers must be installed simultaneously with the berm. Solutions have been engineered but the construction and installation of the riser system is complex. At a typical central installation the number of lines to be tied-in could be about twenty. Their size could range from 36 inches to 8 inches and their purpose may vary from sub-sea flow lines and transportation trunk lines to future spares. Nevertheless, if a pipeline transportation system is chosen, the impact on the class of platform structure is negligible.

Transportation by Tanker

Unlike pipelines, a tanker transportation system can have a major impact on the production platform required. Major elements of a tanker transportation system are the vessels, the mooring system, the loading system, and the crude storage system, all of which have an effect upon configurations.

A primary consideration for a tanker transportation system is whether the proposed production location is in the landfast ice or in the transition zone. Production facilities within the landfast zone create a number of access problems whereas production facilities within the transition zone are more accessible because of the water depth and the open water lee which developes as the ice travels by the structure. In order to optimize transportation tarriffs, arctic tankers will be about 200,000 DWT in size or larger, and require a draft of approximately 27 metres. As a result, these vessels will need a minimum of 30 metres water depth in which to operate. If the structure is in landfast ice, which generally extends to the 20 m water depth, this creates two operational problems for the tankers. One is that the water depth is insufficient, the second operational problem is that tankers continually travelling through landfast ice and over approximately the same route will create large regions of grounded rubble. The solutions to these problems are extremely expensive. One solution is to dredge a channel to the production structure and also a turning basin at the site. Another solution consists of constructing a loading terminal outside the landfast zone and piping crude to this facility. The solution chosen will probably depend on the distance from the production site to an adequate water depth. This distance can be substantial because of the shallow slope of the seabed which, in general, is about one metre per mile.

It may take as much as ten miles to reach a loading terminal from a production site near the edge of the landfast ice. For an economic comparison of these two options the cost of a loading terminal, together with the installation of a pipeline, should be compared to the cost of dredging an adequate navigable channel to the production site and a turning basin at the production platform.

Many of the classes of structures studied in the past for tanker transportation have had harbour configurations. Recent studies have indicated that harbours are no more efficient than the other classes of structure and also, that they are appreciably more expensive. It is unlikely therefore that they will play a primary role in the future development of the arctic.

3.2 The Impact of Production Facilities and Their Installation

The production facilities consist of the equipment placed upon the sub-structure that is required to process crude together with all of the associated support systems, including drilling and storage. The basic systems required are process separation and well injection, power generation, flare systems, life support, accommodation and the drilling package. As shown in Figure 1, the production facilities may be modular, fully integrated, or semi-integrated.

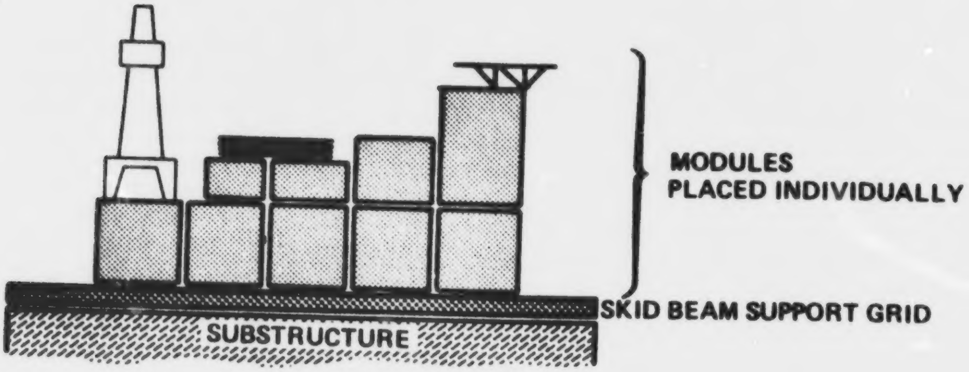
In many offshore areas the cost of the facilities and their installation, hook-up and commissioning is far in excess of that for the supporting sub-structure. The facilities configuration therefore is first determined on an economic basis and the sub-structure is designed to suit. This will not be the case in the arctic as sub-structure costs will be substantial and at some locations there will be little choice with respect to the class of sub-structure to be installed. Nevertheless the type of sub-structure selected can influence the facilities configuration and vice versa.

When discussing the size of facilities, it is perhaps more meaningful to discuss it in terms of area and weight rather than 'throughput' of crude. This is because there can be a substantial difference in the size of facilities required for the same throughput. The difference is a result of the complexity of the process which is a function of the composition of the crude. As a guide, the operating weight of facilities in the arctic will be between 20,000 tonnes and 40,000 tonnes and if the facilities structures are stacked in order to minimize the plan area, the minimum plan area required to support the facilities will be approximately 70 m x 70 m.

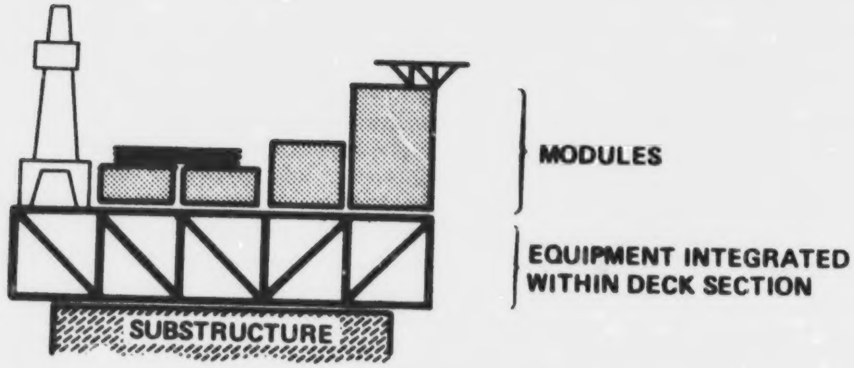
Modular Configuration

The modular configuration consists of packaging the equipment in a number of modules, transporting these by barge to the site and installing them by means of a heavy lift vessel. Because of the short open water season at Point Barrow, there will probably be only forty days available to place the modules on the surface of the sub-structure. Allowing 100% downtime (which includes

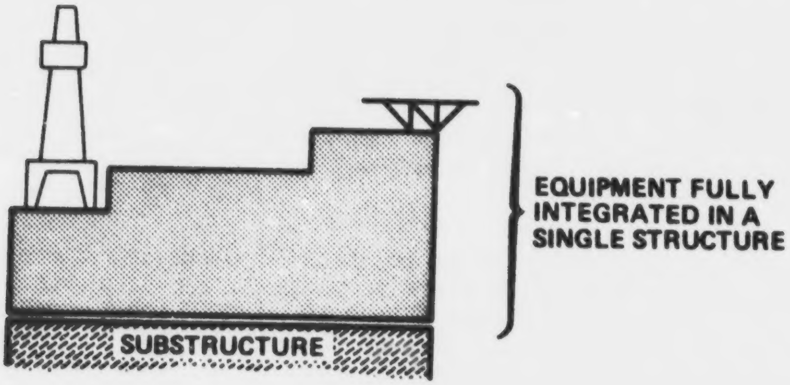
Fig1 FACILITIES CONFIGURATION


MODULES
PLACED INDIVIDUALLY
SKID BEAM SUPPORT GRID
SUBSTRUCTURE

MODULARIZED


MODULES
EQUIPMENT INTEGRATED
WITHIN DECK SECTION
SUBSTRUCTURE

SEMI-INTEGRATED SYSTEM


EQUIPMENT FULLY
INTEGRATED IN A
SINGLE STRUCTURE
SUBSTRUCTURE

INTEGRATED SYSTEM

for bad weather and equipment malfunction) and one day per major lift, this means that the majority of the facilities should be packaged in no more than twenty major modules or lifts. The dry weight of modularized facilities is substantially less than the operating weight and the maximum lift weight of a module will be approximately 1,500 tonnes. Larger modules of course can be fabricated but this means that heavy lift vessels with cranes of capacity greater than 2,000 tonnes will be required in the arctic.

In order to speed up the installation operation the module layout should be based on a rectangular grid such that modules can be placed from at least two sides of the sub-structure and then skidded to their intended location. This process will require a substantial foundation system to be installed on top of the sub-structure to enable the modules to be skidded and to provide a rigid foundation for the modules to limit differential settlement during operation.

The majority of sub-structure concepts proposed for the arctic are suitable for a modular system and generally they will have available a plan area in excess of the minimum requirement.

Integrated Deck

An integrated deck configuration consists of a skeletal frame of steel work into which the complete facilities package is installed. The structure is fabricated as a single unit then tested and commissioned prior to being transported north. In the past such units have been transported on converted tankers because barges of sufficient capacity have not been available. Sub-structures in other offshore locations which have had integrated decks installed have had either a very narrow central support column, or a large enough gap between the legs to enable the deck to be floated over the top of the sub-structure during installation. The deck is either lowered on to the sub-structure by ballasting the supporting vessel or the sub-structure is raised by deballasting, to mate both sub-structure and deck. It is very unlikely that Beaufort Sea sub-structures will have either a narrow central column or legs. Beaufort Sea structures will be much more monolithic than structures in other offshore locations because of the ice loading situation. It is probable that if a fully integrated system is used the system will be fabricated on top of the sub-structure in a protected harbour at a southern location. The sub-structure would therefore be a gravity platform of some description which can be transported by the use of its own buoyancy. There is however, a water depth restriction of the order of 30 m through the route via Point Barrow and the deadweight of a complete process unit on top of a gravity structure may cause problems.

Semi-Integrated Deck

A semi-integrated deck is divided such that a substantial portion of the facilities consist of an integrated deck and the remainder of the facilities are modularized and placed on top. There are a number of advantages and disadvantages to this hybrid system but the impact upon the sub-structure is substantially the same as that of the fully integrated deck configuration.

3.3 The Impact of the Substructure Fabrication and Installation

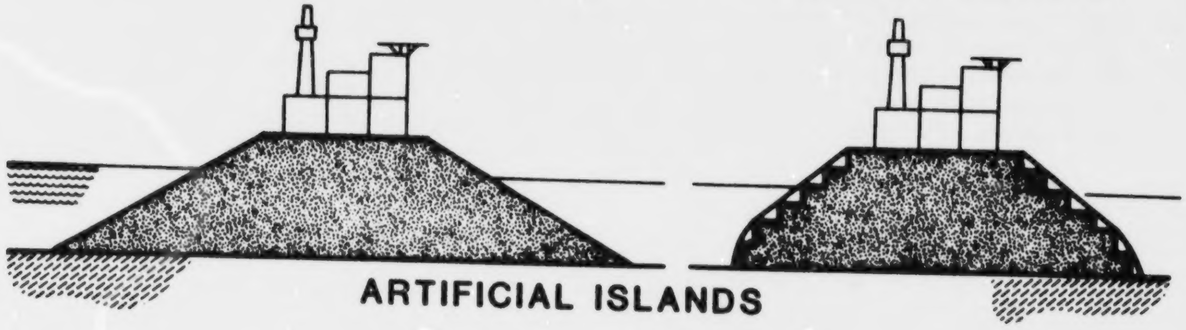
There are basically four classes of production sub-structures which are viable in the Beaufort. These are: artificial islands, berm supported multi-unit structures, berm supported single units and seabed supported single units. Details of these structures are given in Figure 2. All of these classes are gravity structures and all horizontal resistance is provided by their mass. There are numerous variations in concepts provided by their mass. There are numerous variations in concepts within each class but the basic approach required to fabricate and install is similar for all concepts within the same class.

One of the primary differences between the four classes with respect to fabrication and installation, is the location at which the majority of the fabrication work is done. This location is essentially material dependent, in other words it depends on what material the majority of the structure is constructed. If the major portion of the structure is fabrication from steel or reinforced concrete, the associated work will be done at a southern location and transported to the Arctic for installation. If the majority of the structure consists of a sand berm then construction will obviously be performed on location.

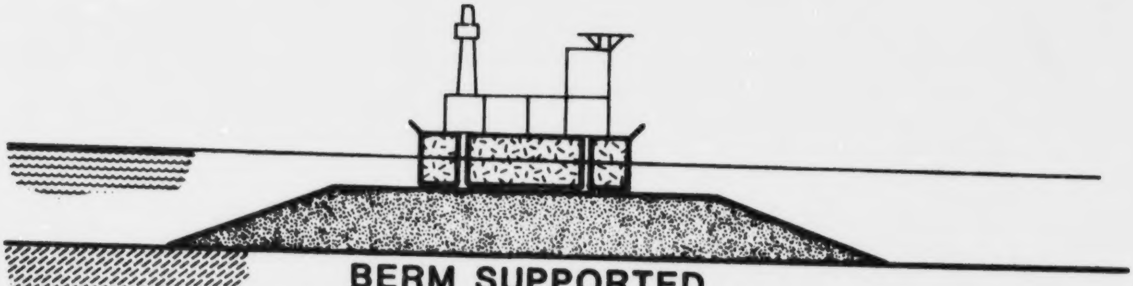
Assuming that within each of the classes mentioned there is a structure which can be designed such that it can be installed and remain serviceable when placed at any location within the Beaufort; the selecton of one of these four potential structures for a particular location will then be based solely upon economics. If one oversimplifies the economic model it can be argued that the two major factors which affect the economics are the initial capital cost of the sub-structure and the time taken to construct. The capital cost is a basic number in economic terms, but the time taken to construct is more subtle. Time influences cost because the longer it takes to complete a facility the longer one has to wait for a return on capital. Therefore, a low captial cost combined with a long construction period can be less economical than a higher initial capital cost with a shorter period to come on stream. To make the following fabrication and installation review more meaningful, the assumptions has been made that a maximum period of five years is required from the initiation of a design to the production of oil. The five years consist of 0.5 years preliminary design, 1 year detailed design, 2.5 years fabrication and 1 year installation and commissioning. These activities are presented as non-overlapped. However, in such a program activities will over-lap, particularly in the fabrication phase which may start as soon as sufficient detailed design has been performed to ensure that abortive fabrication work will not be initiated. Generally any concept which allows for some productin prior to the completion of the primary facility will be more economical than a concept which does not have this flexibility.

For many of the concepts proposed for the arctic, the risk of one year's delay is high. This is because large units may not be able to enter the Beaufort two years out of ten. Further, if the delivery of the facility or waterline penetration system is delayed during a season, there may not be enough time to complete installation. The situation can be improved if ice breaking support is used during the voyage.

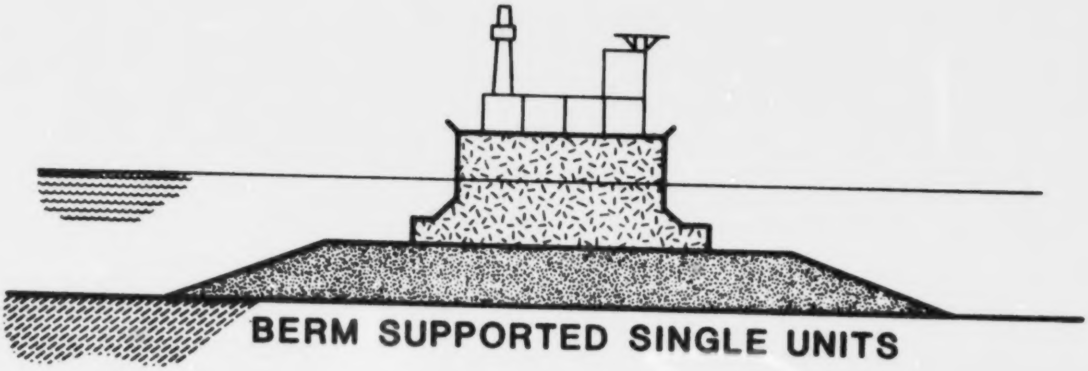
Fig 2 BASIC CLASSES OF SUBSTRUCTURE



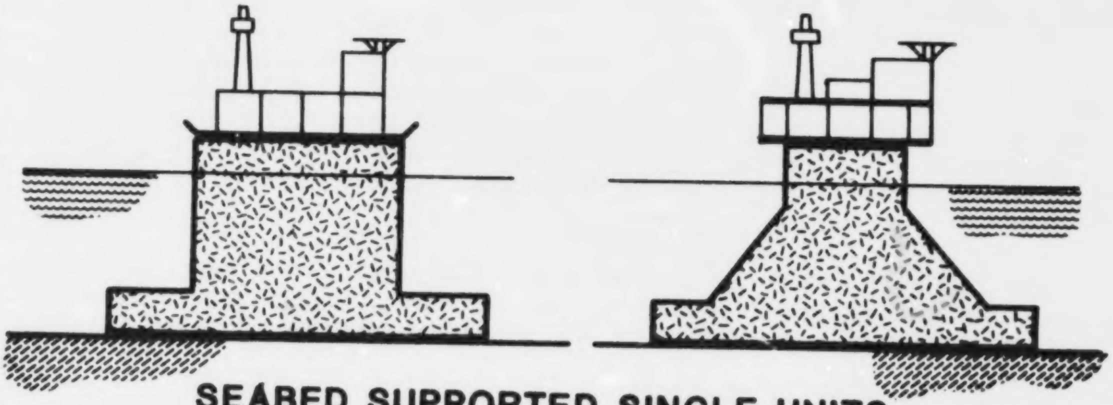
ARTIFICIAL ISLANDS



BERM SUPPORTED
MULTI-UNIT STRUCTURES



BERM SUPPORTED SINGLE UNITS



SEABED SUPPORTED SINGLE UNITS

Artifical Islands

The intent of an artificial island is to create an area above sea level on which can be constructed a typical land based production facility. In the Beaufort such an island would be constructed from dredged sand with additional protection near the waterline. Such an island can be very simple if only constructed from sand placed at a shallow slope with erosion protection placed at the waterline beach elevation. The island can be more complex if sand volume is to be minimized. In this case the side slopes could stabilized by gravel or asphalt dykes with rock armour placed at the waterline. This class of structure would be fabricated almost entirely in the North.

The major construction limitations are time and cost. If one assumes that a conventional dredging spread is used, the volume of material placed per year may be about 10,000,000 cubic metres. With the assumed restraint of a five year project, there willl probably be only three years available for construction. In addition to island construction this allows for one year's design and one year's installation and commission of the facilities. A practical limitation upon island size is probably an artificial island whose volume is approximately 30,000,000 cubic metres.

The cost of fill material is sensitive to many factors such as distance hauled, method of placement, type of dredge, etc. The cost of sand fill can vary from between $10 to $25 per cubic metres. Rock is not easily available and is heavy and difficult to transport. Its cost is approximately $100 to $300 per cubic metre. The cost of a 30,000,000 cubic metre berm could vary from about $300 million to $750 million. Of course, costs of fill may be reduced and volumes greatly increased if new technology such as super dredges are introduced. However, the initial investment is high, and may have to be capitalized over one project as the requirement for similar structures required in the future may be uncertain.

Berm Supported Multi-Unit Structures

This class of structure consists of a sand berm built to about 10 metres below sea level on top of which is placed a structure which penetrates the waterline and supports the facilities. The term multi-unit stems from the fact that the waterline penetrating structure may be fabricated from a number of units which are connected on site.

This is an extremely flexible concept regarding the water penetrating structure. This structure may consist of concrete or steel caissons which form a rectangular perimeter, the core of which is then filled with sand. Or it may consist of a number of ice reinforced barges or converted tankers. Also, as mentioned previously the facilities may be modular, integrated or semi-integrated.

Regarding construction and installation, the size of the berm is limited by the time and equipment available, as is the artifical island class of structure. The onsite connection of the waterline penetrating units could be time consuming and difficult because of the isolated offshore environment. This process could add a year to the project because there may not be time to transport, install and connect the units and construct the system's core prior to installing modules. Therefore, the facilities would be installed eight months later and only then could commissoning of the system begin. If the facilities are integrated or semi-integrated with the water penetrating structure, i.e. if the central core consists of facilities installed on a purpose built barge which forms part of the sub-structure, there is less probability of delay.

Berm Supported Single Units

The berm supported single unit class of sub-structure consists of a single gravity unit which is supported by a sand berm. The single unit may be fabricated from steel or reniforced concrete at a southern location. As with the berm supported multi-unit structure, there is a construction advantage in that the berm and structure may be constructed simultaneously. The unit when insitu may draw between 20 and 30 metres of water and will have a diameter of 150-200 metres. The diameter would depend upon either ice loads, crude storage requirements or the need to provide additional buoyancy to reduce draft during transportaton.

The structure would be substantial and would probably require a purpose built fabrication yard at southern location. The structure would be self buoyant and of relatively shallow draft during tow. There is also an extremely good chance that the facilities could be pre-installed and still cause no draft problems during transportation. Delay due to ice at Point Barrow is still a concern as with the previous class of structure.

Installation of the unit on a sand berm would be a quick operation, only a matter of days. However, the berm top must be level and of consistent stiffness to ensure that load is evenly distributed from the water penetrating unit. To stiffen large structures of this nature to withstand differential settlement or local loss of support is extremely expensive.

Seabed Supported Single Units

The seabed supported single unit if developed for a relatively shallow water depth is identical from a construction and installation point of view to the berm supported unit.

If the structure is developed for deeper water, which is more probable, the major concern is the difficulty of fabricating such a structure and the difficulty in transporting it because of its inherent mass and probable deep draft. There is an economic limit as to how wide one can construct the base in order to provide additional buoyancy to decrease draft. It is also probable that the total cost of a purpose built fabrication yard will be added to the cost of the structure because at the time of construction there may be no guarantee that another structure of this size would be fabricated.

This class of structure minimizes the amount of work in the north but may increase the southern content to an unmanageable degree under the timeframe envisaged.

3.4 Summary of Requirements

Having made certain assumptions with respect to transportation rates, total time available to complete, and that where possible conventional equipment and procedures will be used, the basic requirements of a production sub-structure can be summarized as follows:

Requirements Relating to Facilities and Their Installation

- The minimum plan area required, on top of the sub-structure to accommodate facilities will be of the order of 70 m x 70 m.
- If it is proposed to install the topside facilities in the arctic the facilities, whether they are integrated or modular, should be designed such that they can be installed in 40 days.
- If the facilities are modular there should be a maximum of approximately 20 large modules which will be placed and skidded to their required positions. The concept must ensure that modules can be skidded from two sides of the platform. Piggyback skidding of modules should also be considered. If the core of the concept is sand fill, a substantial grid foundation will be required in order to skid modules and ensure no differential settlement during operation. The maximum operating weight of the facilities will probably be no greater than 40,000 tonnes, the most probable weight will be in the range of 20,000 to 25,000 tonnes. The maximum dryweight of a single module will be approximately 1,500 tonnes.

Transporation System

- A pipeline transportation system will have virtually no impact on the sub-structure concept. If a berm concept is considered, the installation of pipeline risers and J-tubes, etc. will require substantial engineering and will impact the construction of the berm.
- For concepts which are developed primarily for tanker transportation systems the following conditions should be met.:

- A vertical or near vertical face is required which extends 30 meters below the waterline, since 30 metres depth will be required for tanker operations.

- The concept should be a minimum of 180 metres wide at the waterline in order to create an adequate lee for mooring tankers in the transiton ice zone.

- Harbour concepts do not appear to be as efficient or cost effective as open water concepts.

- Allowing for contingency, the storage capacity of the concept will be approximately twice the capacity of the class of tanker considered. It is probable that if development is taking place in the landfast zone a separate tanker loading facility will be required. This structure will be located in the transition zone to ensure adequate operating draft and to minimize loading downtime during the winter months.

Sub-Structure Fabrication and Installation

- The structure should not draw more than 28 metres during tow in order to ensure adequate bottom clearance.

- To adhere to a reasonable overall schedule, assuming the use of existing dredging vessels and equipment, assume that a maximum of 30,000,000 cubic metres of fill can be placed in a three year period.

- If the concept under consideration is constructed primarily from reinforced concrete or steel it will be constructed at a southern location. At present, there is no experience in Canada with construction of structures of the size required and fabrication facilities have to be purpose built. The provision for such a construction facility is on the critical path for any proposed development of this nature. It may not be possible to capitalize these facilities over more than one projects.

Regulations

- It should be assumed that the government will insist that Canadian content for the project is maximized.

- The design of the sub-structure must meet the requirements of the May 1983 Canadian Oil and Gas Structures Regulations and any revision of these regulations in existence at the initiation of the project.

General Design

- The sub-structure must be capable of sustaining local damage without leading to progressive collapse. The configuration should be such that if local damage occurs it could reasonaloy be easily repaired. No downtime should result from such damage.

- A five year program for overall development is envisaged. However, any concept which incorporates a sub-system which can pre-drill wells prior to the installation of the completed production system should be given preference.

- The sub-structure should be designed such that it meets all the functional, scheduling and environmental requirements at minimum cost.

- It is unlikely that adequate foundation conditions cannot be found or prepared, at any potential development site, for any of the classes of structures envisaged. Nevertheless, a soils survey is on the critical path for any proposed development.

- The operational life of the facility will be approximately 30 years and the concepts should be designed such that there will be no significant downtime caused by either maintenance or weather conditions throughout this period.

4. SUITABLE CLASSES OF STRUCTURES AT VARIOUS LOCATIONS

One of the purposes of this paper is to demonstrate that the first stage in selecting a concept is to establish the class of sub-structure that is most suitable at a particular location. There are many variations in configuration within a particular class, some of which are more cost effective than others. However, the consequences of not selecting the best configuration within a class have much less impact than the consequences of not selecting the optimum class of structure.

It is true to say that whatever class of structure is selected it can be designed to resist a defined environment, as this is simply a function of making the configuration heavier or stiffer or larger, etc. The difficult task is to select a concept which not only meets all environmental and functional requirements but one which is also cost effective. Because of the different conditions whcih exist throughout the Beaufort it is reasonable to suggest that there is not single class of structure and therefore no single concept which is suitable for all locations.

As a result of studies performed by the Frontier Division of Dome Petroleum Limited during 1983, it has been found that for the purposes of achieving an overview of the situation, the major parameters which affect the choice of class of structure at various locations are: water depth, the mode of transportation, and the time available. It is difficult to isolate and discuss any of these factors without mentioning its impact upon the other parameters and the only real normalizing influence is cost. But cost is in itself not an input, it can only be an input in the terms "ensure that the least expensive total production scenario which meets all requirements is chosen." The following discusses each of the three parameters in turn and comments upon their impact on their remaining parameters when necessary. A brief description of the most suitable locations for the four classes of substructures described in Section 3 is then given.

Waterdepth determines whether the structure is in landfast ice or in the transition zone. It also determines the available draft for installation and tanker approach. If one accepts that the area required above sea level for facilities is a constant for the same throughput and crude properties, then the water depth becomes the major factor affecting the size of the sub-structure. Large berms are extremely expensive and their cost effectiveness in comparison to other structures decreases with height. Relative to height a berm volume increases to the power of two whereas the volume of a steel or reinforced concrete structure increases approximately linearly.

The mode of transportation only has a significant impact upon the class of sub-structure required if the transportation is by tanker. Either the requirement to create a lee for mooring the tanker in ice, or the storage requirements will determine the diameter of the sub-structure. The artificial island class and the berm supported multi-unit class of structure cannot easily accommodate the tanker transportation, mooring and loading requirements because of the restrictions of available draft. If these classes of structure are chosen as part of a production development then the scenario may also have to include for a separate mooring and loading facility.

Time has a significant effect upon the class of structure to be used. Time is the major factor influencing the mode of transportation of sub-structure units and facilities into the Beaufort and also the offshore construction and installation phases of the project. Because of its influence on construction there is a limiting size of berm which can be constructed economically in a given time using conventional techniques. Time also influences the amount of interest paid on capital and also the time at which the development will become profitable. Therefore, certain development scenarios which require higher capital expenditure but which decrease the overall development period may be more cost effective in the long term.

Without site specific data it is not possible to definitely state that a single class of structure is most suitable for a particular location. However, it is possible to comment with respect to the general trend.

The artificial island class of structure appears to be most suitable in shallower water, about 15 m, or less. This class of structure is not suitable for transportation of product by tanker unless separate loading facility is constructed. The structure is also best suited to a modularized facilities configuration.

The berm supported multi-unit class of structure appears to be most suitable in water depths ranging from 15 m to about 40 m. Transportation of crude by tanker is possible if the water penetrating system is deep enough to allow for tanker access and crude storage, but generally if this is the case the tendency would be to select a berm supported single unit. The structure is suitable for any configuration of facilities.

The berm supported single unit class of structure can accommodate any configuration of facilities and also a pipeline or tanker transportaiton system. The most suitable water depth range is from abut 40 m to 60 m.

The seabed supported single unit class of structure will generally be best suited to deeper water, say depths greater than 50 m. This class of structure can accommodate any form of facilities configuration and the conventional modes of crude transportation.

SECTION TWO

ICE BREAKERS

GULF CANADA'S FOUR NEW ARCTIC CLASS IV ICEBREAKER/SUPPLY VESSELS

by

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ABSTRACT

Starting this year, Gulf Canada Resources Inc. of Calgary, through its wholly owned offshore drilling subsidiary Beaudril, becomes a major operator in the Beaufort Sea.

Beaudril's two Beaufort Sea drilling units, the Conical Drilling Unit (CDU) currently on location and the Mobile Arctic Caisson (MAC) to be delivered in 1984 are supported by four state-of-the art Arctic Class IV Icebreakers/Supply Vessels, representing the world's most powerful icebreaker fleet in private ownership.

The design, construction and capabilities of the vessels, named "Kalvik", "Terry Fox", Ikaluk" and "Miscaroo" are described in this paper.

1.0 INTRODUCTION

BeauDril's two Beaufort Sea drilling units, the Conical Drilling Unit (CDU) and the Mobile Arctic Caisson (MAC), are supported by four state-of-the art Arctic Class IV Icebreaker/Supply vessels, representing the world's most powerful icebreaker fleet under private ownership. The four ships are the Kalvik, Terry Fox, Ikaluk and Miscaroo. Refer to photographs on page 187.

The requirements for marine support of the drilling system were developed in association with the drilling units in late 1980. This led to the decision to build four multi-purpose icebreaker/supply vessels, two of which would be of exceptional power for the purposes of front line ice management. Two designs were developed in the spring of 1981 and subsequent model tests in open water, level ice and ridged ice were preformed in order to optimize the hull forms and propulsion systems for the ships' intended support duties.

All four ships were designed for maximum flexibility of operation. Their capabilities include:

Ice Management	- Most importantly dealing with large pressure ridges prevalent in the Beaufort Sea in the latter part of the season.
Anchor Handling	- Primarily the CDU mooring system with its 15 tonne 'Bruce' anchors.
Towing	- Of drilling units and other floating structures.
Supply	- Of the drilling units with fuel provisions and drilling consumables.

In addition, all the ships meet COGLA regulations as standy-by craft.

The ships have been constructed to Lloyds Register classification the latest Part X - Hull Construction and Safety Regulations and the Canadian Coast Guard ASPPR Arctic Class IV regulations. This Class designation represents an operating season from June 1st to January 31 in Zone 12 (MacKenzie Delta Region), and there is potential for extending the season further into the winter.

The bid documents were issued in September 1981 and construction contracts were signed in December 1981. Three ships were built in Canada and the fourth in Japan.

2.0 M.V. "KALVIK" (AND SISTER SHIP M.V. "TERRY FOX")

2.1 Design and Construction

The Kalvik was designed to GCRI's requirements by German and Milne Naval Architects, Montreal, and built in Victoria, B.C. by Burrard

Yarrows Corporation. The principal particulars of the vessel are an overall length of 88 metres, a breadth of 17.5 metres and a displacement of 6800 tonnes at a draft of 8 metres. Construction started in April, 1982 when the first steel was cut and the first steel unit (double bottom unit) was placed on the berth on June 21st. Kalvik was constructed in 85 units which were assembled on the berth. The launch took place on April 2, 1983 and the superstructure, which was built as a separate unit, was lifted on immediately afterwards. The vessel was drydocked on June 8th for the application of 'Inerta 160', a low friction coating to reduce friction between the hull and ice. Dock trials commenced on June 30th followed immediately by sea trials. Kalvik was delivered on July 22, 1983.

2.2 Hull Form and Performance

The Kalvik's double chine hull form was developed from the requirements to be as operationally efficient as possible in both open water and ice while being capable of simple construction (a minimum of three dimensional plate forming). The bow form incorporates a 'V' section for directional stability during ridge ramming and an ice deflector to shed broken ice laterally, thereby minimizing movement of ice under the vessel and into the propellers. Open screws (i.e. no nozzles) were chosen for their ability to keep the vessel moving with the minimum of backing and ramming in heavy ice conditions. The stern lines have been kept as 'clean' as possible, for good flow into the propellers and backing characteristics in ice. The midship body incorporates an 8° flare angle which enhances open water seakeeping performance as well as reducing resistance in ice. The vessel is fitted with a Wartsila Air Bubbling system to reduce friction between the hull and ice during icebreaking. It can also be used as a bow thruster which together with a stern thruster, make the vessel more maneouverable.

2.3 Propulsion System

The propulsion system consists of 4, 8 cyclinder Stork Werkspoor diesel engines developing a total of 24,000 BHP. These drive twin shafts through Lohmann and Stolterfoht reduction gears. Each shaft is fitted with a Lips controllable pitch propeller. In order to maintain shaft revolutions during ice milling, a 12 tonne flywheel is included in the shaftline. A full electronics control and monitoring system, supplied by Asea, is centered in the engine control room. Auxiliary power is generated by 2 power take-off generators (1000 kw each) driven from the reduction gears, and 3 diesel generators (2 x 750 kw and 1 x 200 kw).

2.4 Anchor Handling and Towing

Anchor handling and towing duties are performed using the large Van der Giessen electric winches located in the winch space. The anchor handling winch has two drums, each capable of a maximum line pull of 200 tonnes. The large 15 tonne 'Bruce' anchors, from the CDU mooring system are handled over the stern roller, onto the large open aft deck of the vessel. The anchors can be moved on the deck by the 25 tonne tugger winch. Anchor pennants can be stowed on a 2 pennant stowage reels located above the winch house. The towing winch, in association with the friction brake has a maximum linepull of 350 tonnes. The 73 mm towing wire is led out over the aft deck and over a towing gate at the stern. Crash rails along each side of the deck provide protection for the crew and the aft deck services, during towing.

2.5 Supply

The aft deck was designed for the stowage of up to 800 tonnes of deck cargo, between the crash rails, for resupplying the drilling units. This type of cargo is generally drill pipe, casing, sea cans, etc. The deck is serviced by two 5 tonne cranes and the tugger winch. Cement and barite cargos are carried in 3 tanks located below the main aft deck, and are discharged to the drilling units via either one of the 2 load/discharge stations on the aft deck, one amidships and one further aft. Cargo fuel is carried in internal tanks and is also discharged via the load/discsharge stations.

2.6 Safety

The vessel has been constructed to meet both Canadian Coastguard Ship Safety regulations and COGLA requirements for a stand-by craft. Safety equipment includes a 37-man Watercraft fully enclosed lifeboat, liferafts and lifejackets sufficient for 300% of ship's compliment and a Lucus 'Hurricane 700D' semi-rigid rescue boat.

2.7 Accommodation

Kalvik has been outfitted with a high standard of accommodation. Each member of the crew has a single cabin and additional accommodation is available for 12 persons in double cabins. The Captain's quarters (Chief Engineers' similar) are located on 'B' deck, one deck below the bridge, and include an office/sitting room and separate bedroom with en-suite bathroom. All other cabins are combined day/bedrooms, the officers cabins having private bathrooms, the crew cabins having shared bathrooms between 2 cabins. A fully equipped galley with cafeteria style serving area is located on the main deck forward with adjacent cool and cold rooms and dry provisions stores. Immediately adjacent to the galley is the mess with seating for 24 persons. Two lounges are available for recreation, one for officers on 'A' deck and the other for crew on the main deck next to the mess. Both lounges include a full entertainment centre (T.V., video, stereo). Other facilities in the accommodation include a sauna, laundry, sick bay and ship's and engineer's offices.

2.8 Bridge Control

The spacious bridge design offers excellent visibility form all 4 control stations. The layout has been designed on the "one man operation" concept, with 4 consoles, 1 forward, 1 aft and 1 in each of the bridge wings, each incorporating all the necessary machinery controls, alarms, navigation aids and communications equipment. The forward control position offers good all round visibility. The aft console is used when a clear view of the aft deck is required, i.e. when anchor handling or backing up to a drilling unit. When coming alongside, control is taken from one of the wings as good visibility along the ship's side is available. All consoles are supplied by Asea. Kalvik is fitted with an ice load warning system for use when navigating in ice. Sixty-four strain gauges welded onto the ship's plating and frames in the bow region, transmit signals via a microprocessor to a real time display, on the bridge, indicating the level of ice loads on the hull. Three levels are indicated by light display, safe, caution and unsafe.

3.0 M.V."IKALUK" (AND SISTER SHIP M.V. "MISCAROO")

3.1 Design and Construction

The Ikaluk was designed to GCRI's requirements, by Robert Allan Ltd. Naval Architects, Vancouver, and built in Japan by Nippon Kokan K.K., Tsurumi Yard. The principal particulars of the vessel are an overall length of 78.95 metres, a breadth of 17.22 metres and a displacement of 5,100 tonnes at a draft of 7.5 metres. Construction started in June 82 when the first steel plates were marked and cut. Ikaluk was constructed in 29 units which were built concurrently between June and September 82, and preoutfitted as much as possible. This enabled NKK to place the first unit on the berth on September 20th and launch the vessel 8 weeks later on November 15th. The vessel was ready for dock trials on March 4th, then was drydocked on March 19th for the application of "Inerta 160" before the sea trials. Sea trials started on April 5th. Ikaluk was delivered on April 27th, 1983.

3.2 Hull Form and Performance

The Ikaluk's hull form was, again, developed from the requirements to be as operationally efficient as possible in open water and ice while being capable of simple construction. The underwater bow form is similar to that of the Kalvik, with "V" section and an ice deflector. This vessel was designed to be of lesser power than the Kalvik, and therefore to enhance the propeller thrusts, nozzles were fitted. Twin rudders fitted immediately behind each nozzle provide excellent maneouverability (turning circle of 2 1/2 ship lengths) which is further improved by an "Omnithruster" type bow thruster and a stern thruster. The Omnithruster can also be used as a bubbler system by diverting the water through a series of air/water mixing valves along the ship's side.

3.3 Propulsion System

The propulsion system consists of 4 - 8 cylinder Wartsila Vasa diesel engines developing a total of 14,900 B.H.P. These drive twin shafts through Lohmann and Stolterfoht reduction gears. Each shaft is fitted with a Lips controllable pitch propeller inside a fixed "Kort" by Prime Mover Controls, Vancouver. Auxiliary power is generated by 2 power take-off generators (1,000 kw each) driven from the reduction gears, and 3 diesel generators (2 x 395 kw and 1 x 250 kw).

3.4 Anchor Handling and Towing

A "waterfall" type combined anchor handling/towing hydraulic winch was chosen for the Ikaluk. The winch, as supplied by Burrard Iron Works, has two (2) anchor handling drums each capable of a maximum of 160 tonnes line pull, and 2 towing drums each capable of a maximum of 150 tonnes line pull. Towing and anchor handling arrangements, aft deck services and resupply capabilities are similar to the Kalvik.

3.5 Accommodation

Ikaluk has the same high standard of accommodation as the Kalvik, but in a little less space. However, each crew member has a single cabin, and additional accommodation is available for 12 persons in 2, 6 berth cabins. All cabins have combined day/bedroom with separate washroom. Crews cabins have shared washrooms. Other facilities are similar to the Kalvik.

4.0 M.V. "KALVIK" AND M.V. "TERRY FOX" EQUIPMENT AND PARTICULARS

Designed and constructed in accordance with the following regulatory authorities:

- Canadian Coast Guard	ASPPR Arctic Class 4
- Lloyds Register of Shipping	100-A1 Icebreaker/Offshore Tug-Supply Ship

4.1 General Particulars

L.O.A.	88.0	M
Breadth	17.5	M
Depth to Main Deck	10.0	M
Load Draft	8.1	M
Displacement at Load Draft	6860	Tonnes
Lightship Weight (Wet)	4803	Tonnes
Deadweight	2057	Tonnes

4.2 Capacities

Fuel Oil (Ship Service & Cargo) - 98%	1650	Tonnes
Fresh Water	237	Tonnes
Ballast/Drill Water	1468	Tonnes
Bulk Barite/Cement	102	M^3
Max. Deck Cargo	800	Tonnes

4.3 Propulsion

4 x 6000 B.H.P Stork Werkspoor diesel engines driving twin shafts through Lohmann and Stolterfoht reduction gears. Each shaft is fitted with a Lips controllable pitch propeller.

4.4 Endurance

Speed (open water)	- 2 Engines	13.3 knots
	- 4 Engines	15.6 knots
Endurance	- Heavy Icebreaking	33 days (approx. 50 tonnes/day)
	- Open Water	55 days (approx. 30 tonnes/day)

4.5 Other Particulars

Constructed from EH36 modified high tensile steel with excellent low temperature properties - around 300 Joules at -40°C notch toughness.

Auxiliary Power: - 2 x 1000 KW P.T.O. generators
2 x 750 KW ship's service generators
1 x 200 KW emergency generators

Wartsila air bubbler system/bow thruster.

500 HP Stern thruster.

Van der Giessen winch package including:

- Towing winch and friction brake - maximum line pull 350 tonnes.
- Anchor handling winch - 2 drums, each with maximum line pull 200 tonnes.
- Tugger winch, powered capstans and stowage reels.

ASEA Electronic controls package.

Stern roller.

34 x 13 M clear deck space.

2 x 5 Tonne Hagglund Wartsila deck cranes.

Navigation equipment includes:

- 2 x Decca radars.
- JMC radio direction finder.
- Sperry doppler fog.
- 2 x Marconi HF/SSB radios.
- Alden weather fax.
- 2 x watch receivers.
- Magnavox satellite navigation system.
- Bendix wind speed indicator system.
- 2 x Honeywell echo sounders.
- 2 x Sperry gyro compasses.
- 3 x Spilsbury VHF/AM radios.
- Wulfsberg VHF/AM radio.
- Wagner auto pilot.
- Weir-Jones ice load warning system - 64 strain gauges.

Accommodation for 22 crew and 12 supernumeries.

Wagner steering gear and single centreline rudder.

Fire monitors.

Xenon searchlights.

Inerta 160 hull coating.

5.0 M.V. "IKALUK" AND M.V. "MISCAROO" EQUIPMENT AND PARTICULARS

Designed and constructed in accordance with the following regulatory authorities:

- Canadian Coast Guard	ASPPR Arctic Class 4
- Lloyds Register of Shipping	100-A1 Icebreaker/Offshore Tug-Supply Ship

5.1 General Particulars

L.O.A.	78.95 M
Breadth	17.22 M
Depth to Main Deck	9.70 M

	Summer (open water)	Winter (ice)	
Load Draft	8.160	7.532	M
Displacement at Load Draft	5852	5107	Tonnes
Lightship Weight (Wet)	3954	3954	Tonnes
Deadweight	1898	1153	Tonnes

5.2 Capacities

Fuel Oil (Ship Service & Cargo) - 98%	1325 Tonnes
Fresh Water	152 Tonnes
Ballast/Drill Water	1175 Tonnes
Bulk Barite/Cement	142 M^3
Max. Deck Cargo	1200 Tonnes

5.3 Propulsion

4 x 3725 B.H.P. Wartsila Vasa 8R32 diesel engines driving two shafts through Lohmann and Stolterfoht reduction gears. Each shaft is fitted with a Lips controllable pitch propellor working inside a fixed nozzle.

5.4 Endurance

Speed (open water) - 2 Engines	11.88 knots
- 4 Engines	14.69 knots

Endurance - Heavy Icebreaking	33 days (approx. 40 tonnes/day)
- Open Water	55 days (approx. 24 tonnes/day)

5.5 Other Particulars

Constructed from EH36 modified high tensile steel with excellent low temperature properties - around 300 Joules at -40°C notch toughness.

Auxiliary Power: - 2 x 1000 KW P.T.O. generators.
2 x 395 KW ship's service generators.
1 x 250 KW ship's service generators.

Omnithruster type bow thruster/air bubbling system.

Stern thruster.

Burrard Ironworks double drum towing/anchor handling winch capable of bollard pull of 140 tonnes on towing drums and 150 tonnes line pull on anchor handling drums, for handling 15 tonne bruce anchors.

Capability for handling and stowing 3-inch anchor chain.

Stern roller.

34 x 13 M clear deck space.

2 x 5 tonne Hydralift deck cranes.

2 x 12 tonne-pull tugger winches.

Navigation equipment includes:

- 2 x Decca radars.
- JMC radio direction finder.
- Sperry dopper log.
- 2 x Marconi HF/SSB radios.
- Alden weather fax.
- 2 x watch receivers.
- Magnovox satellite navigation.
- Bendix wind speed indicator system.
- 2 x Honeywell echo sounders.
- 2 x Sperry gyro compasses.
- 3 x Spilsbury VHF/FM radios.
- Wulfsberg VHF/AM radio.
- Wagner auto pilot.

Accommodation for 22 crew and 12 supernumeries.

Wagner steering gear and twin rudders.

Prime mover controls.

Fire monitor.

Xenon searchlights.

Inerta 160 hull coating.

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ADVANCES IN ARCTIC ICEBREAKER DESIGN

by

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1. SUMMARY

The economics of resource exploration and production in the Arctic regions dictate the need for cost effective icebreaker vessel support. Recent developments and extensive full scale performance evaluations show convincingly that the introduction of innovative design features are effective in meeting this need. As a result, the power requirements for an icebreaker with year-round Arctic operational capabilities are being reduced considerably by actual demonstrations of icebreaking performance of the following two ships, the Canmar Kigoriak and the Robert LeMeur.

In this paper, the authors discuss the novel design features of the Canmar Kigoriak, industry's first purpose-built Arctic icebreaker, specifically; hull form, ice management systems, manoeuvreability, propulsion requirements and resultant performance.

On the basis of the very successful full scale performance results of the Canmar Kigoriak, a second generation Arctic icebreaker, the Robert LeMeur, has been designed, built and evaluated. The systematic variations from the Kigoriak proven design features incorporated within the Robert LeMeur are outlined.

The Kigoriak and Robert LeMeur Research Programs were specifically aimed at evaluating and assessing features of these two ships in actual Arctic conditions and provide unique full scale knowledge for the development of future operations of polar class vessels.

Future developments based upon research results are presented in concept form for a polar icebreaker and icebreaker/oil tanker.

2. INTRODUCTION

Icebreaker development over the past 100 years has focused upon providing support to commercial ice transiting shipping activities. The required icebreaker performance specifications have therefore evolved from experience gained in performing such duties.

The use of icebreakers supporting frontier resource exploration activities in the Arctic has identified the need for ships which are far more ice-capable and cost effective. To date, the Canmar Kigoriak and the Robert LeMeur are the largest proven purpose built icebreakers in operation to support offshore resource exploration in the Arctic. A new design philosophy has been pursued to meet the mission profile requirements which incorporates features which differ radically from past icebreaker design practice. These features are outlined in the following sections and an assessment of their effectiveness is given based upon testing and evaluation under actual full scale Arctic conditions.

PRINCIPAL PARTICULARS

FEATURE	MEASUREMENT
LENGTH (OVERALL)	900 m
LENGTH (AT WATERLINE)	84.2 m
BREADTH (MOULDED)	17.25 m
BREADTH (OVER REAMERS)	19.25 m
DEPTH	10.0 m
DRAFT (MAXIMUM)	8.5 m
SHAFT POWER (HULL LUBE OFF)	12.2 MW
SHAFT POWER (HULL LUBE ON)	11.8 MW

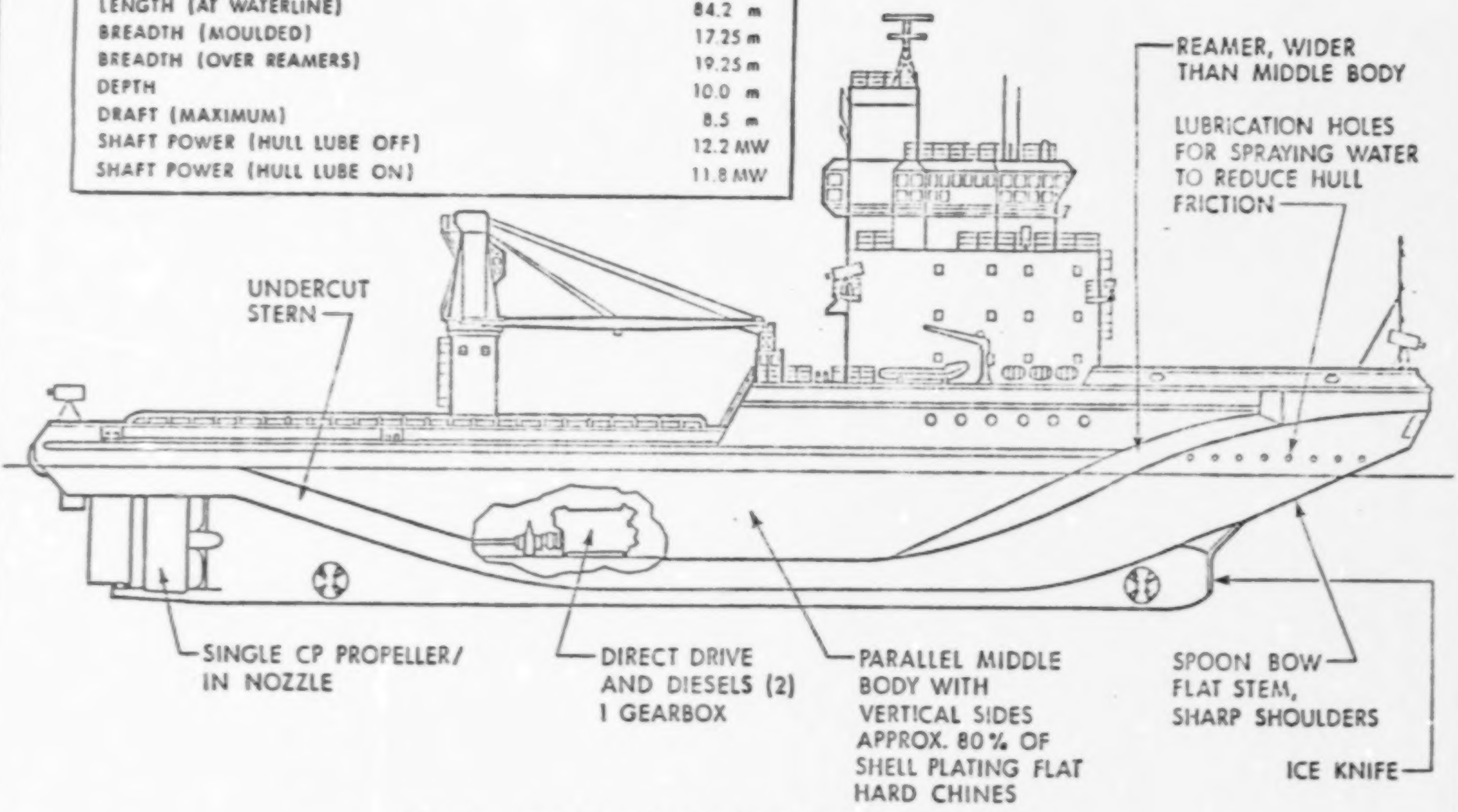

REAMER, WIDER THAN MIDDLE BODY
LUBRICATION HOLES FOR SPRAYING WATER TO REDUCE HULL FRICTION
UNDERCUT STERN
SINGLE CP PROPELLER/ IN NOZZLE
DIRECT DRIVE AND DIESELS (2) 1 GEARBOX
PARALLEL MIDDLE BODY WITH VERTICAL SIDES APPROX. 80% OF SHELL PLATING FLAT HARD CHINES
SPOON BOW FLAT STEM, SHARP SHOULDERS
ICE KNIFE

FIG. 1: KIGORIAK GENERAL ARRANGEMENT

3. INNOVATIVE DESIGN FEATURES

Embodied in the design of the Canmar Kigoriak are new concepts never before built into a full scale vessel. These are highlighted in Figure 1. Based upon the successful testing and evaluation of these, a second prototype vessel, the Robert LeMeur was subsequently developed and built. Incorporated within her design is a systematic variation of these same features together with the introduction of new concepts.

These innovative design features are outlined in the following sections. Shown in Figure 2 and 3 are General Arrangements of the Canmar Kigoriak and Robert LeMeur respectively for reference purposes.

3.1 Spoon-Shaped Bow

The application of the concepts into the design of the modern icebreaker Canmar Kigoriak is primarily based upon the design requirement to break thick ice using minimum energy. The development of this concept also includes the sharp shoulder at the junction of the bow and midbody section. In addition, an icebreaker bow design of this type can include reamers which are discussed separately.

Another advantage identified, from a performance point of view, with the development of the spoon bow is a reduced susceptibility to getting stuck in the ice due to the reduced amount of crushing of the ice, particularly at the shoulders.

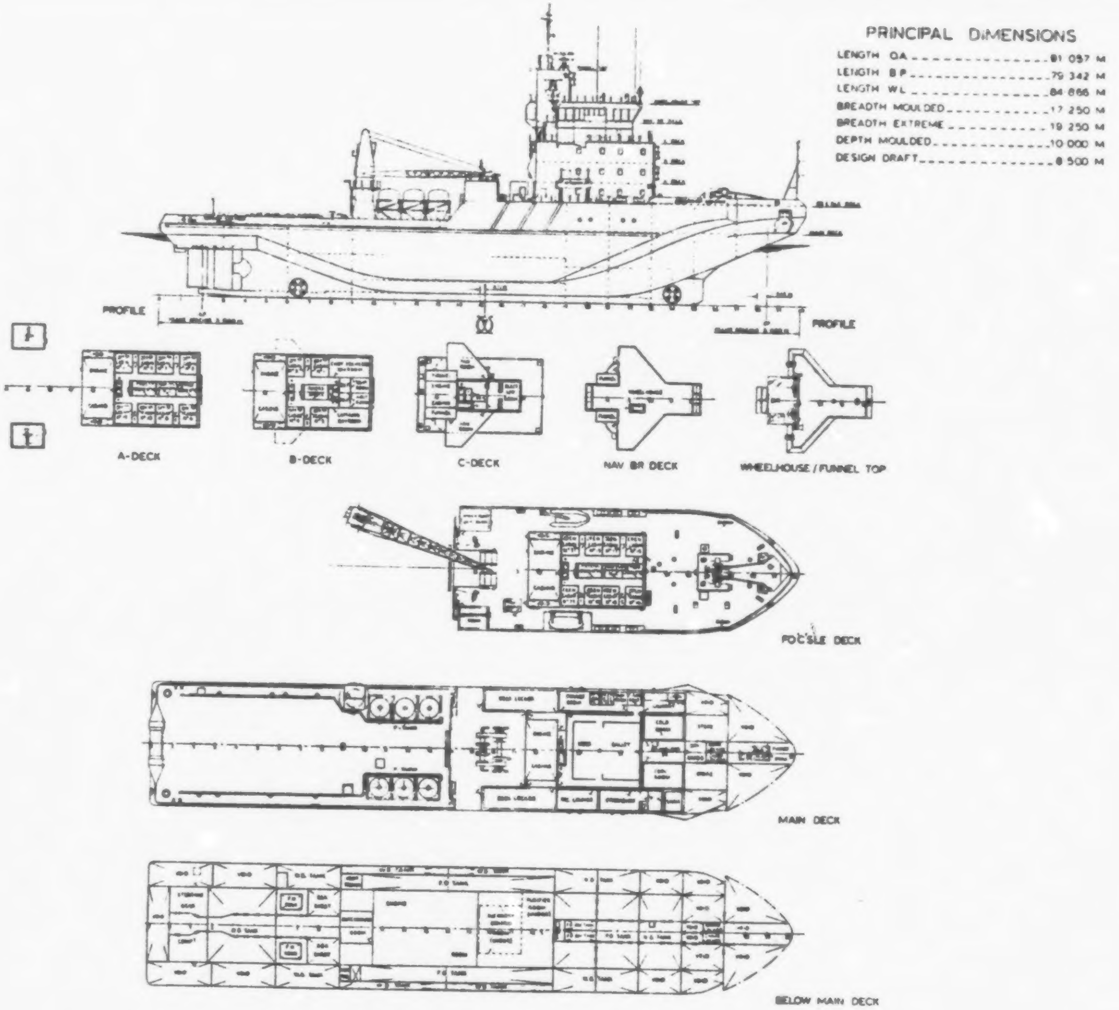
Following the successful initial application of this concept on the Canmar Kigoriak, a modified version using a shorter bow length and shallower bow angle was developed for the Robert LeMeur. These changes were to further reduce resistance and also to meet the constraints imposed by an operating draft limitation resulting in a flatter shape.

Also of interest is the fact that the relatively shorter bow length associated with the spoon shape makes it possible to extend the parallel midbody forward which results in an increase in the displacement of an icebreaker of given length. This has the benefit of increasing the ships' earning capability as deadweight will also be increased.

3.2 Reamers

The reamers form an integral part of the spoon bow concept and application in the design of Canmar Kigoriak and Robert LeMeur.

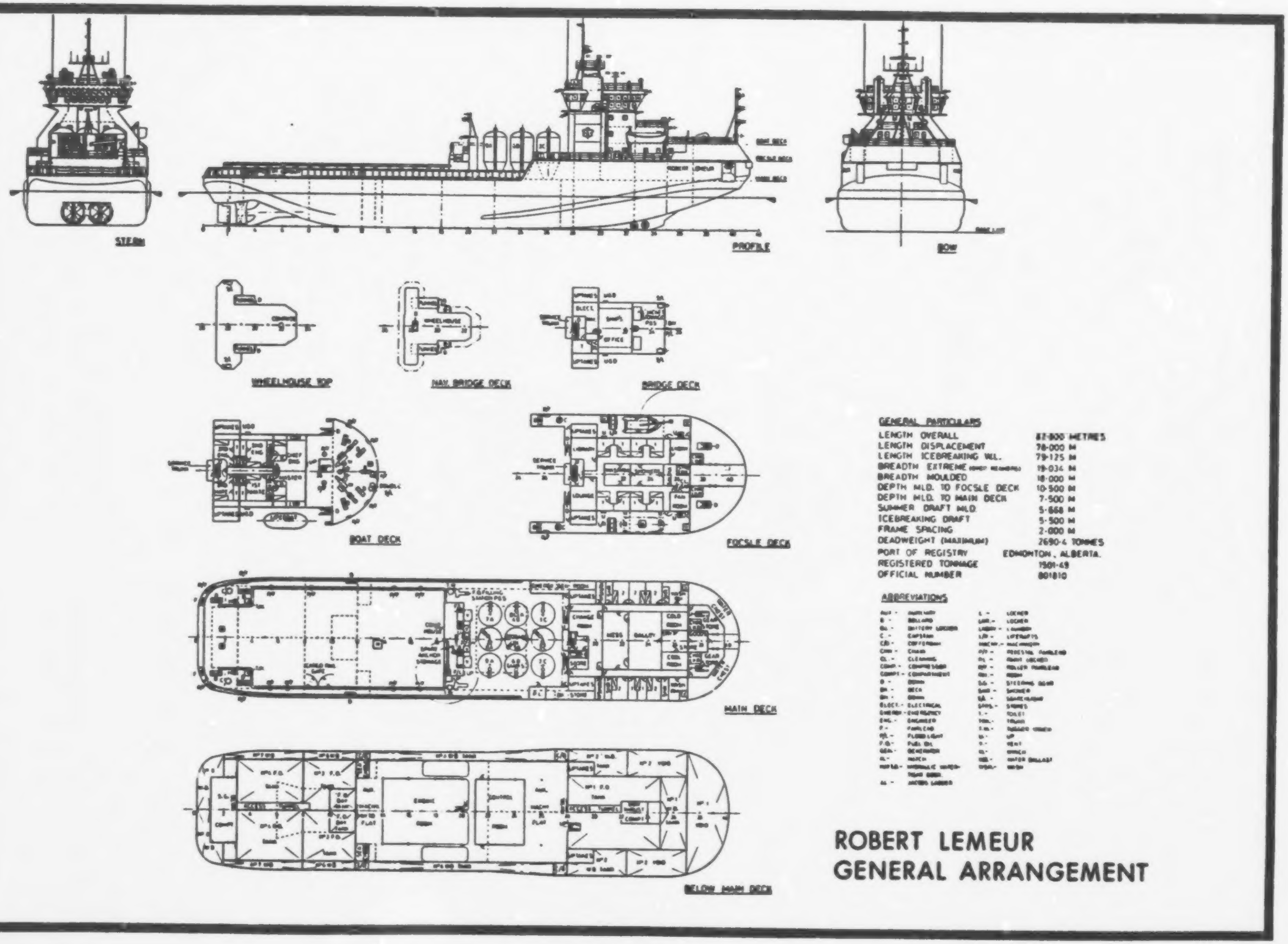
Located along the forward shoulders, reamers are extension of the spoon shaped bow form beyond the ships moulded breadth which are then faired back into the parallel midbody. The bow is therefore wider than the midbody, but only locally.


PROFILE
PROFILE
A-DECK
B-DECK
C-DECK
NAV BR DECK
WHEELHOUSE / FUNNEL TOP
FO'C'SLE DECK
MAIN DECK
BELOW MAIN DECK

PRINCIPAL DIMENSIONS

LENGTH OA	81 057 M
LENGTH B P	79 342 M
LENGTH W L	84 866 M
BREADTH MOULDED	17 250 M
BREADTH EXTREME	19 250 M
DEPTH MOULDED	10 000 M
DESIGN DRAFT	8 500 M

FIGURE 2 CANMAR KIGORIAK GENERAL ARRANGEMENT


STERN
PROFILE
BOW
WHEELHOUSE TOP
NAV. BRIDGE DECK
BRIDGE DECK
BOAT DECK
FOCSLE DECK
MAIN DECK
BELOW MAIN DECK
BOAT DECK
FOCSLE DECK
MAIN DECK
WHEELHOUSE
OFFICE
ELECT.
LOUNGE
MESS
GALLEY
ENGINE ROOM
CONTROL ROOM
ABBREVIATIONS

GENERAL PARTICULARS

LENGTH OVERALL	87·800 METRES
LENGTH DISPLACEMENT	78·000 M
LENGTH ICEBREAKING W.L.	79·125 M
BREADTH EXTREME	19·034 M
BREADTH MOULDED	18·000 M
DEPTH MLD. TO FOCSLE DECK	10·500 M
DEPTH MLD. TO MAIN DECK	7·500 M
SUMMER DRAFT MLD.	5·668 M
ICEBREAKING DRAFT	5·500 M
FRAME SPACING	2·000 M
DEADWEIGHT (MAXIMUM)	2690·4 TONNES
PORT OF REGISTRY	EDMONTON, ALBERTA.
REGISTERED TONNAGE	1501·49
OFFICIAL NUMBER	801810

ROBERT LEMEUR
GENERAL ARRANGEMENT

FIGURE 3

The widely recognized capability of breaking a track wider than the ships' beam is therefore introduced without the drawback of wedging the ship during astern operations.

Benefits associated with the use of reamers include increased lubrication and therefore reduced resistance along the ships' side and significant improvements in ship manoeuvreability in ice.

The advantages obtained from the use of reamers far outweigh the slightly greater breadth of track that must be broken.

For the purpose of studying the reamer, widths of 1.0 metre and 0.5 metre have been incorporated in the design of Canmar Kigoriak and Robert LeMeur respectively.

3.3 Ice Knife

Design considerations of the forefoot stopper at the base of the bow include the need to impact a splitting force into the consolidated section of a ridge or multi-year ice which has not failed in bending during bow ride-up. The ice knife must also be configured to prevent excessive ride-up/penetration of the ship resulting in getting stuck and/or beaching of the vessel.

In this context, different configurations have been built-in to the Canmar Kigoriak and Robert LeMeur for the purpose of obtaining a better understanding of the design requirements relating to the forefoot.

3.4 Parallel-Sided Midbody

The conventional icebreaker usually has a flared midbody to overcome the high resistance associated with ice crushing in the vicinity of the forward shoulders as well as for manoeuvreability considerations. Other disadvantages include an expensive, rather complex construction at the junction of bow and midbody. Since this design requirement is overcome by the spoon-bow with or without reamers, it is now possible to build icebreakers with parallel vertical sides.

This feature has therefore been adapted in both Canmar Kigoriak and Robert LeMeur for the purpose of testing and assessing this type of feature which will be prevalent in large transportation system vessels. It is also of benefit in that it facilitates the construction of these vessels with consequent reductions in capital cost and delivery time.

3.5 Stern Configuration

First introduced in the Canmar Kigoriak is the undercut stern which is designed to reduce the suction of ice into the ducted propellers as well as permit backing of the ship into heavy ice.

Performance results were mixed which resulted in the introduction of the propulsion island on the Robert LeMeur design. This feature is intended to reduce the amount of ice-propeller interactions in thick level ice ahead and whilst backing.

3.6 Ice Management Systems

These systems, varying widely in complexity and cost, are all primarily intended to reduce friction in one form or another.

Only a water lubrication system was incorporated in the Kigoriak design. This system, developed and applied for the first time by Dome/Canmar on a ship, has been extremely successful at reducing resistance and contributes in part to the fact that the ship's performance has exceeded even the most optimistic performance expectations.

The water lubrication system discharges a screen of water from strategically placed holes at the bow onto the snow/ice surface. Friction is therefore reduced with the added benefit that the greatest reductions in friction and therefore resistance occur with colder temperatures and/or thicker snow cover. The same system has been fitted on the Robert LeMeur with similar success.

Further enhancements in ice management systems incorporated into the Robert LeMeur have been previously discussed, by Churcher et al (1983).

These include hull lubrication below the waterline and a low friction hull coating to reduce resistance, the use of air bubbler systems to reduce ice-propeller interactions and a heeling system to improve manoeuvreability.

3.7 Propulsion System

The novel aspect of both the Canmar Kigoriak and Robert LeMeur has been the introduction of mechanical systems of standard design.

The Canmar Kigoriak is propelled by two diesel engines driving a single ducted controllable pitch propeller through a twin-input single output gearbox.

A single screw configuration was selected to overcome the problems of constantly milling ice experienced on the outboard screws of twin screw and triple screw icebreakers. The single screw is surrounded by a duct to give greater thrust at low speed and to provide protection to the propeller by limiting the size of ice blocks capable of interacting with it.

Following the very successful use of this system, a similar concept was adopted for the Robert LeMeur using a twin screw installation developed as a result of a draft limitation imposed on the design. Systems enhancements over those initially tested on the Canmar Kigoriak include the provision of increased inertia to shield the machinery from ice impact transit peak forces and improvements to the control system by way of much faster machinery response times.

4. PERFORMANCE ASSESSMENT

Through extensive full scale monitoring and research programs conducted by Canmar personnel over the past four years, the novel design features incorporated in the Canmar Kigoriak and Robert LeMeur have been evaluated and assessed against design requirements. The information derived from these programs represents a unique source of data on which to assess and determine design criteria. As such, actual results are of proprietary nature. However, a qualitative overview is given in the following sections.

4.1 Level Ice Performance

Improvements in this category are a direct result of the reduced resistance. This reduction is attributable to improvements resulting from the design of the spoon bow and reamers coupled with the reduction in friction associated with the effective use of ice management systems. The result of such innovations and development is that the Robert LeMeur is capable of breaking the same ice thickness near its limiting capabilities as the original hull of the Canmar Kigoriak. This represents a reduction in the power requirement of the order of 40% to break a given ice thickness.

The introduction of parallel vertical sides has been successful in that no detrimental effects have been observed.

The backing performance associated with the undercut stern concept is not as good as that obtained with conventional icebreaker designs.

On the Canmar Kigoriak, backing results in heavy ice/propeller interactions occurring as well as a tendency for the ship to break out of the channels due to the single screw, single rudder installation.

Improvements built into the Robert LeMeur design to overcome these results include a modified stern design incorporating the stern wedge. This has resulted in a significant reduction in the amount of ice being ingested in the propellers whilst backing. The wedge, as presently configured, however does not permit backing in level ice nor does it allow the ship to break out of the channel going astern.

The two designs tested and evaluated to date cover almost the complete range of possibilities in backing performance. From these full scale test results, design criteria may be formulated from which designers can build-in desired backing characteristics into an icebreaker.

4.2 Ridge Performance

Energy considerations govern the performance of icebreakers in ridges. In this context, design development has focused on the vertical stopper or ice knife configuration. Design considerations relate to the need to maximize use of the ships kinetic energy in destroying the ridge while preventing the ship from getting stuck. Two configurations of vertical stopper have been tested in which detailed measurements have been made to derive energy dissipation. These are of significant benefit in determining the optimum design.

The reduced power requirements have a significant bearing on two aspects of ridge performance:

- the reduced available astern thrust increases the need to further study extraction capability requirements, and,
- the lower available thrusts result in slower ship accellerations leading to potentially longer ramming cycles.

Solutions to the above are currently available to the designer through the use of ducted propellers offering much greater thrust at low speed ahead and astern together with the proper application of such ice management system as water lubrication, low friction coatings and heeling systems.

4.3 Ice Management Systems

Numerous auxiliaries to reduce the friction component of resistance have been proposed and/or used. These include heeling and trimming systems, bow propellers, air bubblers, water lubrication, air/water lubrication and low friction coatings. Canmar's experience is based upon the development of water lubrication systems coupled with the use of low friction coatings. These have proven to be very effective and reliable in enhancing performance independently of ships speed.

Similarly, they have also been beneficial in preventing the vessels from getting stuck in ridges. Only under extreme cases has the heeling system been required.

4.4 Manoeuvreability

To date, little research has been conducted into the criteria affecting the manoeuvreability of ships in ice. The turning characteristics of icebreakers are therefore a result of a particular design rather than an input requirement.

Of particular interest are the turning capabilities of the Canmar Kigoriak and Robert LeMeur because of their vertical parallel sides and long parallel waterline at the icebreaking draft. Test results have shown that the turning diameters of both vessels are as good and/or significantly better than state-of-the-art icebreakers depending upon the size of reamers, hull form and the use of heel. This is a particularly important finding when one considers the results of the Manhattan where the turning diameter was found to increase from state-of-the-art levels in 0.9 metre ice thickness to about 80 ship lengths in 1.2 metre ice thickness. Results obtained from the Robert LeMeur which is 1:3.5 scale model of an Arctic VLCC do not show such an adverse trend.

The results of current research based upon test results indicate that turning diameters of the order of 6 ships' lengths in 1.8 metre thick ice are achievable.

4.5 Propulsion System

The introduction of the geared diesel installation driving a controllable pitch propeller on the Canmar Kigoriak has proven to be very successful under year round Arctic service.

The nozzle configuration has been very effective at limiting the size of ice pieces going through the propeller. The protection thus offered significantly reduces the amount and degree of shock loading to which the propulsion system is subjected and permits a propulsion system of standard lower fuel consumption type design to be used. Difficulties associated with the use of nozzle such as loss of thrust due to chocking of the nozzle, can be satisfactorily overcome through careful design of hull form.

The successful use of controllable pitch propellers on icebreakers is a significant development since it provides the same capabilities as a diesel-electric propulsion system with the added benefit of reduced capital cost and reduce risks of sustaining propeller damage during reversals. Enhancements introduced into the Robert LeMeur propulsion system have been most effective at shielding the machinery in the case of the added inertia. The fast response time controls have been beneficial in substantially improving the vessel ramming cycle as well as preventing the ship from getting stuck.

5.0 FUTURE DEVELOPMENTS

Canmar's approach to develop the technology for Arctic shipping has been to proceed in stages based upon full scale developments.

This is because, from experience, model tests and analytical models alone are of limited use in extrapolating the design of Arctic ships.

New concepts for future Arctic ships are being developed based upon the testing and evaluation of Canmar Kigoriak and Robert LeMeur which will provide the performance capabilities at required economical levels for successful resource development. Shown in Figures 4 and 5 are the lastest artist concepts of the Polar X-10 icebreaker and Arctic tanker respectively.

The X-10 icebreaker concept incorporates the latest developments of the features presented and has been conceived for unsupported, unrestricted year round operation with particular accent placed upon relability and performance in ice. The key objectives in developing such an icebreaker are as follows:

1. Pursue the development of technology in stages which are verified in full scale prior to the next step.
2. Demonstrate the feasibility of year-round Arctic marine navigation.
3. Provide full scale input into the development of performance requirements for the full range of Arctic vessels and including multi-year ice.
4. To increase industry's ability to move structures in the Arctic.
5. Provide year round emergency and support services in the Arctic.

From this, arctic marine transportation systems can be developed at lesser risk and cost to industry and government.

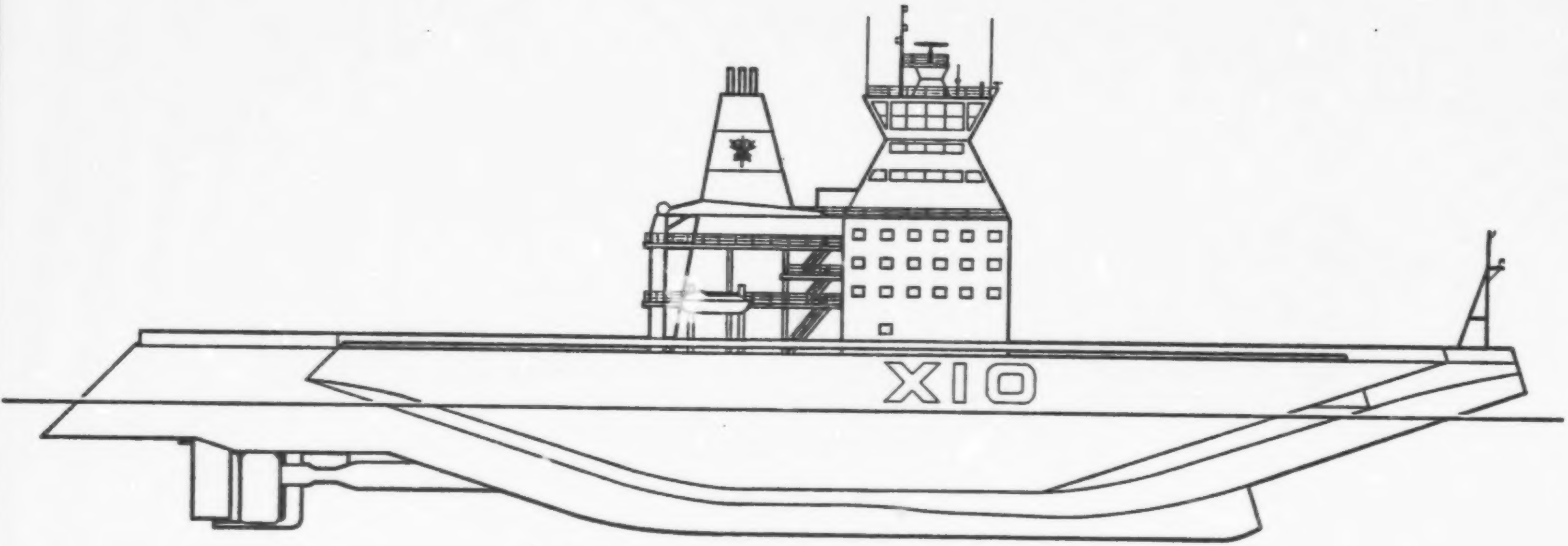


Fig. 4 POLAR X10 ICEBREAKER

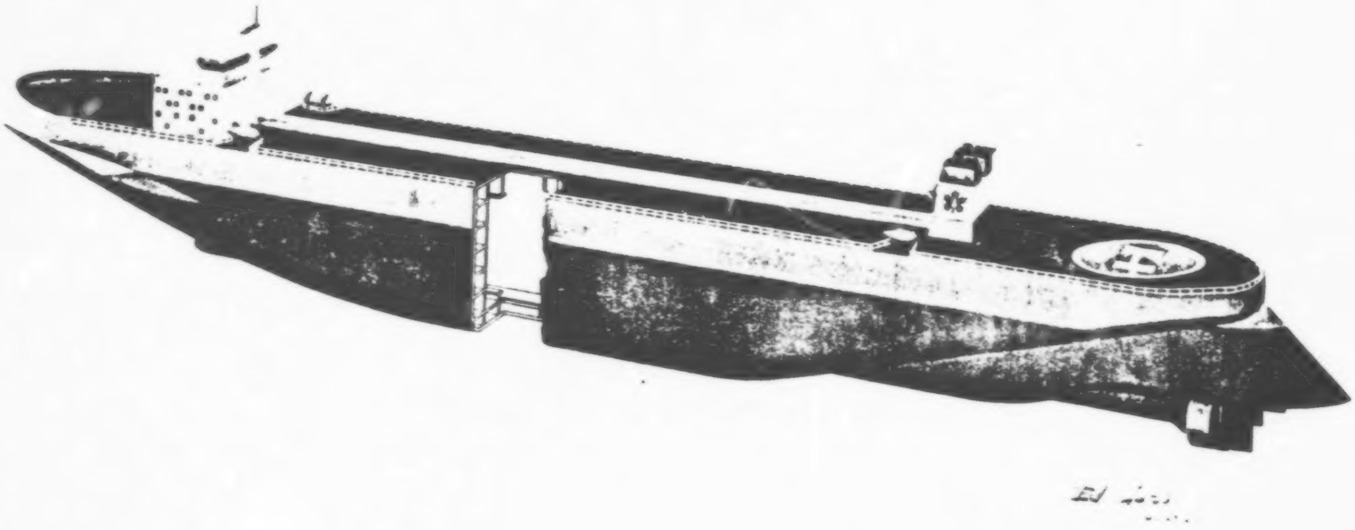


Fig. 5 ARCTIC TANKER

6.0 CONCLUSIONS

6.1 Innovations in hull form combined with the use of ice management systems have significantly reduced resistance in breaking level ice.

6.2 The reduction in resistance associated with the increased thrust available from a nozzle propeller installation has resulted in power reduction requirements of at least one-half to two thirds based upon CASPPR requirements for year round large icebreaking vessels.

6.3 The reamer has proven to be effective at reducing resistance and improving manoeuvering without detrimental effects to astern performance.

6.4 Ice management systems are a cost effective means of improving icebreaker performance.

6.5 The geared diesel driving a controllable pitch propeller has been proven to be a reliable propulsion system under Arctic service conditions.

6.6 The line of icebreaker development pursued by Canmar represents a viable cost effective means of support to Arctic Offshore Exploration.

6.7 A full scale year round navigation demonstration and research program by an X-10 type icebreaker would be cost effective based upon the learning experience gained to date.

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FUTURE U.S. COAST GUARD SHALLOW-DRAFT ICEBREAKER REQUIREMENTS IN ALASKA

by

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ABSTRACT

The continued development of Alaska's North Slope and adjacent seas portends an increased federal government presence in the marine environment. Increased marine traffic in support of exploration, discovery and production of petroleum products can lead to obvious impacts on several interrelated programs of the U.S. Coast Guard. The cumulative effect of these influences would require a shallow-draft icebreaking capability that is not provided by the existing U.S. polar icebreaker fleet. Although shallow water icebreaker design is in its infancy, the recent acquisition of small icebreakers by several nations reflects an emerging technology. A critical challenge for the U.S. Coast Guard will be to carefully mesh its required capabilities with the design limitations associated with shallow-draft icebreaking.

1. INTRODUCTION

A firmly committed and continuing Arctic quest for oil is a reality in the 1980's. One indicator is that the last areas of Alaska's Outer Continental Shelf (the Barrow Arch and Shumagin regions) will have been offered for lease to the oil and gas industry by 1987. Industry's staggering investment in bids for tracts and in the exploratory phases of resource development indicate a long-term, aggressive involvement in Alaska's marine environment.

Such projections of Arctic resource development can influence and stimulate the growth of a vastly expanded marine support and transportation system. Initial offshore activities, particularly in Navarin and Norton Basins, may require year-round operations by ice capable support vessels. Increased exploration and production along the North Slope and further into the Beaufort and Chukchi Seas will call for enhanced seasonal logistics support by larger tug and barge convoys. In the early 1990's it is conceivable that commercial marine carriers will commence year-round transits of Bering Sea oil to the continental U.S. Also, the potential Alaskan traffic related to development, production and westward transportation of hydrocarbons from the Canadian Arctic cannot be ignored.

These scenarios can impact on a host of U.S. federal responsibilities that are associated with the traditional roles and missions of the U.S. Coast Guard. However, there is a distinct lack of icebreaking capability within the existing Coast Guard inventory to meet these perceived present and future needs in Alaska's coastal waters. The existing Coast Guard icebreaker fleet consists of large polar capable ships having drafts in excess of 8.5 meters (28 ft). These vessels will be ineffective to meet most emergency requirements due to the wide, shallow continental shelf along Alaska's northern coast and limiting depths of the western coastal regions. Other resources including the law enforcement vessel STORIS and several offshore buoy tenders are shoal draft but lack enough power for extensive ice operations.

The statements and opinions in this paper are the personal ones of the author and do not necessarily reflect the official views of the U.S. Department of Transportation and the U.S. Coast Guard.

2. IMPACTS OF ALASKAN DEVELOPMENT ON THE U.S. COAST GUARD

Continued development of Alaska's arctic and subarctic coastal waters may potentially impact upon several interrelated U.S. Coast Guard programs. Federal responsibilities, particularly those transportation related, are spread among several agencies, but the majority of activities within the marine environment fall under the Coast Guard's span of control. Figure 1 suggests the major programs (which execute the broad responsibilities of the Coast Guard) that will be most affected by what happens in Alaskan marine waters. The cumulative effect of these increased activities would require more capable supporting resources, including a multi-mission, shallow-draft icebreaker.

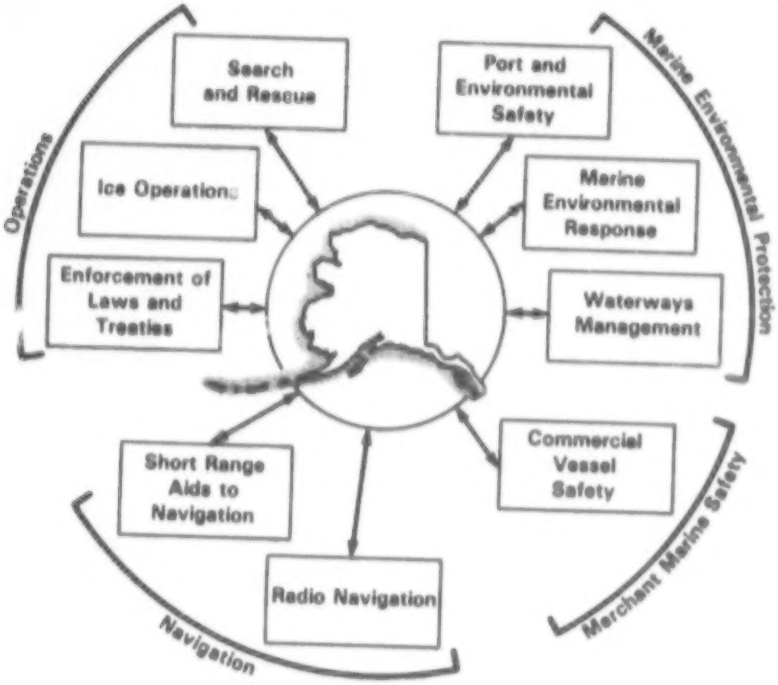
Operations
Search and Rescue
Ice Operations
Enforcement of Laws and Treaties
Port and Environmental Safety
Marine Environmental Response
Waterways Management
Marine Environmental Protection
Commercial Vessel Safety
Merchant Marine Safety
Short Range Aids to Navigation
Radio Navigation
Navigation

Figure 1. U.S. Coast Guard Programs Impacted by Increased Development of the Alaskan Marine Environment

2.1. Merchant Marine Safety

The anticipated growth in commercial activities in Alaskan waters can increase the numbers and types of inspections required under the Commercial Vessel Safety program. The development and construction of artificial islands, unique offshore drilling rigs, arctic workboats, tankers and other unusual support equipment may well initiate new marine safety regulatory measures. An effective, year-round response for the investigation of accidents and violations will be mandatory.

2.2 Marine Environmental Protection

The development and support of an arctic energy production/exploration system will require extensive planning and construction of shoreside services bases. Coast Guard responsibility under the Port and Environmental Safety program will be the monitoring of port activities and the enforcement of a variety of laws and safety regulations (e.g. supervision of hazardous cargoes and the investigation of accidents). Establishment of new port safety stations may or may not be required but the requirements of monitoring safe operations will surely increase.

Impacts on the Waterways Management program will include increased administration of federal anchorages and safety zones, and the possible extension of vessel traffic systems beyond Prince William Sound. The future development of traffic management schemes (for both foreign and domestic vessels) will be an essential factor in providing the necessary balance between resource development and protection of the Alaskan ecosystem.

Within its Marine Environmental Response program the Coast Guard will have an increasing requirement to inspect tank farms, oil terminals, transfer locations, production platforms and submarine pipelines. An increasing number of inspections will be performed in remote regions where shallow water and difficult ice conditions are the norm. Industry will be required to respond to oil spills or blowouts within the framework of contingency plans that have been reviewed by the Minerals Management Service and the Coast Guard. However, a federal onscene presence and an emergency backup response capability cannot be disregarded. Alternative Coast Guard pollution response systems based on selected scenarios are being developed. The problems associated with logistics along the coast add credence to the need for a small, highly capable icebreaker. The ability to operate close aboard an artifical gravel island or other structures in the event of a major spill would appear to be a significant Coast Guard requirement.

2.3 Navigation

A major consideration in support of increased marine traffic is the development and maintenance of a reliable system of aids to navigation. Both the Short Range Aids to Navigation and Radionavigation (long range aids) programs of the Coast Guard will be influenced even by modest growth in Alaska's marine waters. Potential increases in aids to navigation support in Bristol Bay, Norton Sound and Kotzebue Sound will be closely linked to successful resource development (petroleum and minerals) far removed from the Prudhoe Bay area. Impacts may also be felt by an increased demand for services in the western Alaskan Peninsula-Dutch Harbor area due to an emerging domestic fishing industry.

Maintenance of remote radar beacons and fixed visual shore aids could be ideally supported by a shallow-draft icebreaker with an embarked helicopter. One advantage of this utilization would be the freeing of Alaskan buoy tenders so they might respond to increased demands in primarily ice-free waters. Long range aids, such as mini-LORAN-C systems that are designed for specific regions await expanded vessel traffic.

2.4 General Operations

Search and rescue on the ice-covered waters of arctic Alaska has been minimal. Projected increases are very difficult to predict. However, the increased use of commercial vessels that are highly ice capable will not totally relieve the Coast Guard of its search and rescue mandate. While the private sector will be expected to shoulder part of this SAR responsibility, the extraction of beset vessels in serious danger will require traditional federal response. Higher levels of fishing and petroleum activities within the marginal ice zone of the Bering Sea will clearly increase the SAR response requirement for western Alaskan waters.

Several factors indicate necessary increases in the Enforcement of Laws and Treaties program as it applies to Alaska. Developing domestic and foreign fisheries will require enhanced aircraft and vessel surveillance efforts in the coming decades. Retreat of both foreign and domestic fishing vessels into the Bering Sea ice for fishing or loading operations will require a greater pursuit capability. The potential utilization of Alaskan waters by foreign oil tankers and other large vessels may also necessitate additional U.S. presence to assure compliance with a host of U.S. laws and treaties.

The Ice Operations program will be involved in the entire range of activities related to Alaskan marine development. This program encompasses the administration and operation of the federal polar icebreaker fleet. Responsibility for planning future icebreaking capability required to support roles and missions in the Arctic and Antarctic rests entirely within the scope of this program. Additionally, close monitoring of trends in marine traffic in Alaskan waters will be required to adequately plan for needed domestic resources. A careful analysis of the cumulative effect of all Coast Guard missions in Alaska's ice-covered regions will potentially lead to definitive operational requirements for a shallow-draft icebreaker.

3. POTENTIAL SHALLOW-DRAFT ICEBREAKER CAPABILITIES

Table 1 is an overview of the primary capabilities of a Coast Guard shallow-draft icebreaker that would be required to accomplish many of the multi-mission tasks suggested in section 2. Of prime importance will be a continuous icebreaking capability of at least 60-80 cm (2-2.6 ft) in depths averaging 6-7 meters. This should allow access to most shallow water areas of the Alaskan coast. The ship should be capable of operating along the shallow North Slope shelf inside the shear zone that separates the pack and fast ice. Although this will be a seasonal requirement from June to October, the vessel can be expected to experience some first-year ice up to 1 meter thick. An additional capability will be to transit the Bering Sea year-round anticipating conditions of 100 percent ice concentration and ice 1.0-1.2 m thick. Occasional multi-year ice conditions encountered would be avoided through effective reconnaissance.

The requirements to conduct law enforcement and search and rescue operations necessitate an all-weather open water design with a minimum 15 knot speed. The capability to serve as a helicopter platform is a critical feature that is directly linked to effectively meeting most projected missions in Alaska. A shallow-draft vessel and helicopter team will provide access to all activities on the continental shelf and to many remote areas as well. To be effective the shallow-draft icebreaker must also include capabilities to monitor foreign traffic, to act as a command and control platform during pollution incidents, to deliver pollution control equipment and to tow offshore in emergencies. All missions will require an onboard information system which will enhance the ship's routing and navigation in ice-covered waters.

Table 1. Potential Capabilities of a Shallow-Draft Icebreaker

- Deep-Ocean Transits to the Alaskan Coast.
- Icebreaking Operations in 20-Foot Depths (6 Meters).
- Class 2-4 Icebreaking Capability with a 12-15 Knot Cruising Speed and 60-90 Day Endurance Between Refueling.
- Conduct and Coordinate Search and Rescue Operations.
- Provide Aids to Navigation Support.
- Act as a Command and Control Platform During Marine Pollution Incidents.
- Conduct Enforcement of Laws and Treaties in the Marginal Ice Zone.
- Serve as a Helicopter Platform for Single Aircraft Operations.
- Provide Support for Teams To Access and Inspect Structures on the Outer Continental Shelf.
- Conduct Sea Control and Port Security in Wartime or Times of National Emergency.

Table 2. Modern Shallow-Draft Icebreaking Vessels (Drafts Not Exceeding 5 Meters)

Class	Country	Year	Length (m)	Beam (m)	Draft (m)	SHP	Displ. (Tons)
Griffon	Canada	1970	71.4	14.9	4.7	4000	2944
Ale	Sweden	1973	46.0	13.0	5.0	4750	1488
Kapitan Izmaylov	USSR	1976	56.5	15.7	4.2	3400	2045
Kapitan Chechkin	USSR	1977	77.6	16.3	3.3	4490	2240
Katmai Bay	USA	1978	42.7	11.4	3.7	2500	660
Seili	Finland	1979	43.0	12.2	4.0	2000	932
Baltica	Sweden	1982	54.9	12.0	3.7	3200	1238
Kapitan Evdokimov	USSR	1983	76.5	16.6	2.5	5170	2150

4. SHALLOW-DRAFT ICEBREAKER TECHNOLOGY

Table 2 presents a summary of government vessels built since 1970 that have shallow water icebreaking capabilities. All have drafts not exceeding 5 meters which would allow their access to much of the Alaskan coast discussed in this paper. None incorporate all of the characteristics listed in Table 1 - endurance and open water characteristics being significant shortcomings in a majority of the classes. However, a review of the vessels in operation today will provide a glimpse of the state of the art in shallow-draft icebreaking.

4.1 Sweden and Finland

The Swedish icebreaker ALE built by Wartsila of Finland operates on Lake Vanern and was designed for a maximum continuous icebreaking capability of 80 cm (2.6 ft). High maneuverability, a high shaft horsepower to displacement ratio and moderate freeboard make this vessel superior for meeting the winter navigation requirements in the shallow waters of Lake Vanern.

Sweden has recently built a specialized vessel worthy of note. BALTICA is a heavy navaids tender capable of icebreaking in Swedish ports and shallow coastal waters. The ship was designed with a traditional forward working-deck and a 12 ton electro-hydraulic crane. BALTICA has a controllable pitch main propeller, two transverse thrusters (fore and aft) and a heeling system. An integrated maneuvering system, incorporating rudder, propeller and bow thruster, provides excellent handling performance in confined waters while servicing aids or icebreaking.

Three channel servicing vessels of the SEILI class are operated by the Finnish National Board of Navigation. They service aids to navigation along Finland's lengthy coast and, although low-powered, are capable of continuously breaking 50 cm (1.3 ft) of ice. Buoys are lifted aboard and serviced aft of the main superstructure. These vessels have a high bow and low fantail that are typical features of many anchorhandling supply ships found throughout the world.

4.2 The Soviet Union

Significant shallow water icebreaking capability has been provided to the Soviet Union by the designers of the Finnish shipbuilder Wartsila. Since 1976 one class of harbor icebreakers and two unique classes of river icebreakers have been constructed. All have been built with an air bubbling system and each was designed for specific shallow water operations.

Three harbor icebreakers of the KAPITAN IZMAYLOV class are designed to be effective in 1 meter ice. A relatively low shaft horsepower to displacement ratio might appear to limit these vessels, but they have proven useful in northern harbors and ice-clogged channels. Their large displacement hull, rugged construction and ample freeboard make them ideal for winter operations in coastal waters.

The KAPITAN CHECHKIN class of six river icebreakers was designed for service on the Volga-Baltic waterways and Siberian rivers. These vessels represent a major departure from traditional, small icebreaker design with the incorporation of a 3.3 m (10.7 ft) draft and a triple screw/rudder arrangement. An automatic lowering system for the masts, radar and other aerials allows for passage under many of the low bridges over Siberian waterways. A 2:1 shaft horsepower to displacement ratio provides a continuous icebreaking capability of an estimated 65-70 cm (2.1 ft) of ice.

In December 1980 a contract was signed by Wartsila to design and construct a new class of vessels that would have a draft shallower than any previous icebreakers. The KAPITAN EVDOKIMOV class of seven ships is quite barge-like in profile with a low superstructure and minimal freeboard being prominent features. A continuous icebreaking capability fo 80 cm (2.6 ft) coupled with a 2.5 meter draft allows access to most Siberian rivers and deltas. These vessels are also designed to operate [illegible] temperatures that reach -50 C. Although limited to icebreaking in confined waters well inshore, they exhibit remarkable capabilities and represent a significant advancement in the design of specialized icebreakers.

4.3 Canada and the United States

The GRIFFON is classified by the Canadian Coast Guard as a medium icebreaker and aids to navigation tender. Although low-powered for an icebreaker, GRIFFON is well suited for Great Lakes operations involving servicing aids and breaking ice up to 70 cm thick. Its multi-mission capability is particularly enhanced by an ability to land a helicopter on a small flight deck located aft of the main superstructure. GRIFFON is also capable of all-weather operations on the open Lakes whose conditions are not unlike those experienced in many coastal areas.

The new, 43 meter KATMAI BAY class icebreakers of the U.S. Coast Guard are designed for icebreaking and multi-mission tasks on the Great Lakes and along the U.S. East Coast. Several vessels have broken 70 cm (2.3 ft) of ice in the continuous mode (Brigham,1983). Contributing to this performance for such a small vessel is a modern icebreaking hull form, an air bubbling system and a higher shaft horsepower to displacement ratio (3.8:1). However, the limited fuel endurance, small crew size and low freeboard of these ships make them unsuited for extended, coastal operations off Alaska.

5. DESIGN CONSIDERATIONS

The U.S. Coast Guard will encounter many challenges in attempting to design a multi-mission vessel with a shallow water icebreaking capability. It would appear difficult to constrain the overall length to less than 60 m (200 ft) because of the basic requirement for all-weather capability in open water (and in a remote geograhical region) and an ability to land a helicopter. A review of Coast Guard missions and shoreside support capacity make it clear that such a ship must be able to independently transit the entire

Alaskan coast. However, it is also obvious that the large displacement/high horsepower of a traditional icebreaker hull form will be hard to achieve considering the draft restriction (a probable 5 meter maximum). A fuel capacity that eouates to a 60 to 90 day endurance will also be difficult to incorporate in a low displacement hull.

Several other significant problems that must be addressed during the design process include:

- The effects of ice between the ship's bottom and the seabed during operations in very shallow water. A possible requirement will be an ice-strengthened bottom which will compound the displacement/draft problem.
- The resistance effects of ice flow around the ship's body and under the hull while continously breaking ice in shallow water.
- The increased interaction between ice and the propeller/rudder arrangement, and a potential reduction in thrust (Juurmaa, 1982).
- Minimizing weight by using light materials for the superstructure, flight deck and associated deck equipment. Additionally, the propulsion machinery must provide maximum shaft horsepower, but be as light as technically feasible.

Final solutions to each of the above problems cannot be adequately predicted. As the design process proceeds inevitable tradeoffs will be required if the maximum draft restriction remains final. An iterative process will aid in reaching compromises between key operational characteristics and their inherent design limitations. One possible result may be a more specialized vessel than is the norm for traditional U.S. Coast Guard cutters.

6. THE FUTURE

The continued development of Alaska's North Slope and adjacent Outer Continental Shelf, including the Beaufort and Chukchi Seas, can potentially have a broad-based effect on the U.S. Coast Guard organization. Many have acknowledged that industry and the State of Alaska will expect that the federal government will insure adequate resources are available to meet traditional responsibilities such as search and rescue, enforcement of laws and treaties, marine environmental response and port and environmental safety. However, industry will be responsible for developing icebreakers, ice capable support vessels and adequate platforms to support an expanded marine transportation system.

The utilization of advanced surveillance systems such as satellites and side looking radar (aboard long range aircraft) will contribute to a federal response in a primarily support role. Although potentially effective these systems clearly do not substitute for a viable, onscene presence. Existing U.S. polar icebreakers are adequate for limited deep water operations during the less severe arctic summer However, marginally adequate resources are now available to respond to emergency operation in Alaska's ice-covered shallow seas.

The exploration and development of the Alaskan marine environment must be monitored closely if the future support needs of federal missions are to be adequately planned. An 8 to 10 year lead time is estimated for the proper budgeting, design and construction of a shallow-draft icebreaker. Thus, an enhanced U.S. Coast Guard response capability in the western arctic many well hinge on an accurate synthesis and analysis of both government and industry forecasts for development.

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SECTION THREE

MONITORING, DATA COMPILATION AND DATA DISTRIBUTION

ICE SURVEILLANCE PROGRAM
TO SUPPORT
THE NORTH ALEUTIAN SHELF C.O.S.T. WELL #1

by

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ABSTRACT

ARCO Alaska, Incorporated is operator of the 1982-83 Bering Sea Continental Offshore Stratigraphic Test (C.O.S.T.) Well Program. During 1982, two wells were drilled. The first well, St. George C.O.S.T. Well No. 2 (55.5°N - 165.5°W), was spudded on May 19, 1982, and finished on September 2, 1982. The second well, North Aleutian Shelf C.O.S.T. Well No. 1 (56.25°N - 162°W), was spudded on September 8, 1982, and was completed on January 15, 1983. Because it was anticipated that operations at the North Aleutian Shelf Well site would extend into the ice season, which begins in early January, an ice surveillance program was initiated. The purpose of the ice surveillance program was to allow the drilling season to be extended, yet ensure that the drilling rig was provided with sufficient warning of a potential sea ice intrusion, so operations could be terminated without the drilling rig encountering ice. The ice surveillance program developed for the North Aleutian Shelf C.O.S.T. Well consisted of:

1. A review of available historical ice-edge data including satellite imagery.
2. Development of a probabilistic scheduling model.
3. Development of a statistical ice-edge motion model.
4. Aerial surveillance of ice-edge using an aircraft equipped with side looking airborne radar (SLAR).
5. Development of a system to manage the flow of ice-edge data.
6. Development of contingency plans for abandoning the well in the event of an ice intrusion.

1. INTRODUCTION

In June 1980, ARCO Alaska, Incorporated, as operator for a group of petroleum industry participants, initiated plans to drill a series of three Continental Offshore Stratigraphic Test (C.O.S.T.) Wells in the Bering Sea. Plans called for drilling wells in the St. George Basin and North Aleutian Shelf during 1982 and for drilling a well in the Navarin Basin during 1983.

Because of the water depths in each basin and the harsh environmental conditions, a severe weather semisubmersible drilling rig, the SEDCO 708, was contracted to drill the wells. Studies performed to analyze the interaction between sea ice and rigs of the SEDCO 708 design concluded that it would not be feasible to operate the SEDCO 708 in ice conditions prevalent in the Bering Sea. Thus, an ice-free operation was dictated. Further, it was decided to define the ice-edge as the southernmost extent of any ice. It was also determined that 12 to 15 days would be required to allow an orderly abandonment of the well and removal of all subsea equipment.

Preliminary studies of the ice conditions and the drilling schedule indicated there was a high probability of operations continuing into the ice season. Thus, an ice surveillance program was initiated. This program consisted of developing a statistical ice-motion model, contracting for ice-edge surveillance using side looking airborne radar (SLAR), implementing a data management plan, and developing contingency plans for abandoning the well in the event of an ice intrusion.

2. PROBABILISTIC SCHEDULING MODEL

In planning the C.O.S.T. Well program, a need was identified to evaluate the scheduling of the program in a probabilistic fashion. To satisfy this need a computer program based on the QGert[1] simulation language was constructed. The program allowed the user to input time estimates for each individual task in the form of minimum, most likely, and maximum times to complete. Using these input data, the program was designed to simulate the schedule and to produce histograms showing the probability of completing any given task as a function of date.

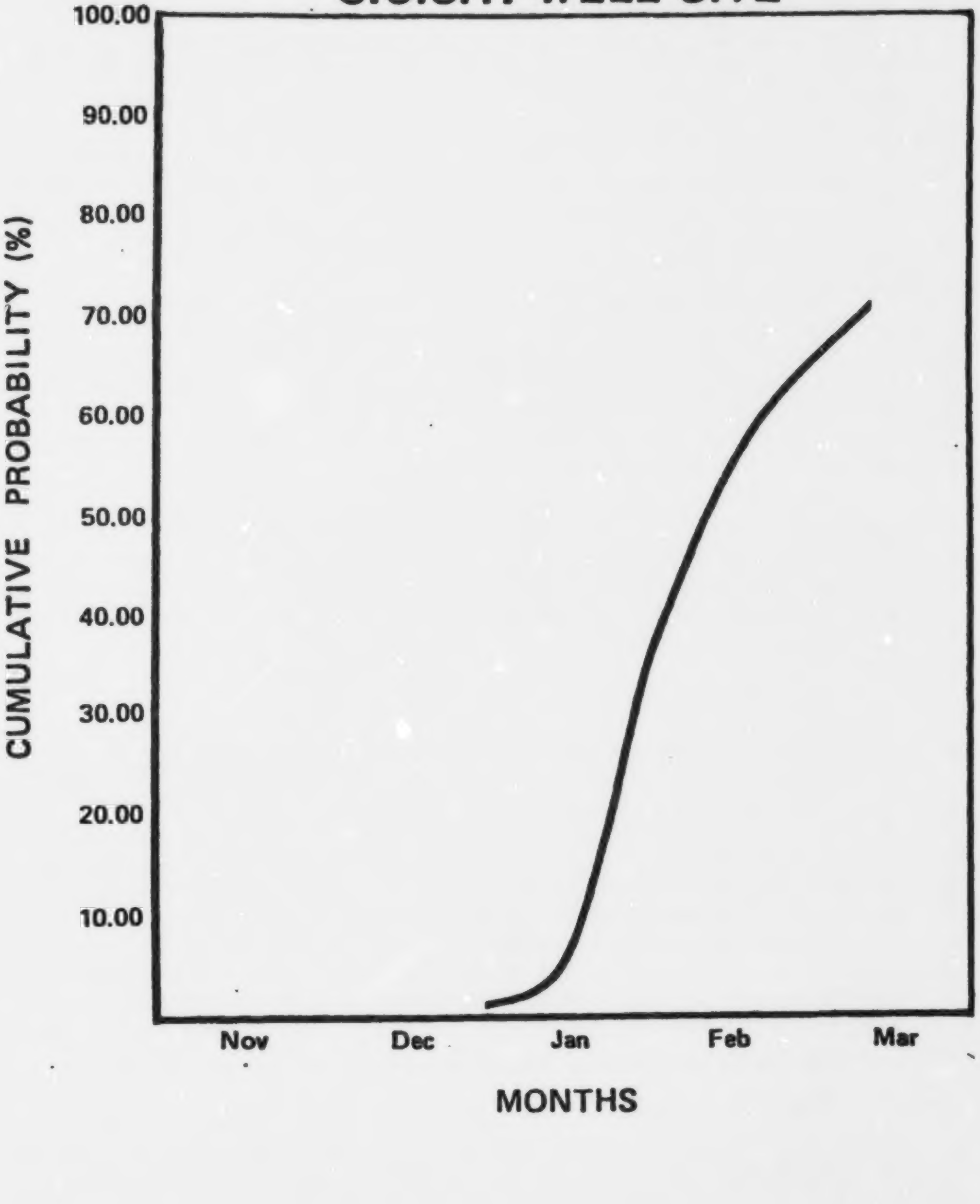
Runs of the model using the expected rig transit schedule (from Capetown, South Africa to Dutch Harbor, Alaska), rig-up time, and the preliminary well design for the St. George and North Aleutian wells showed there was approximately a 30 percent chance of being at the North Aleutian site later than the onset of the ice season (mid-to-late January).

3. REVIEW OF HISTORICAL ICE-EDGE DATA

Because the SEDCO 708 semisubmersible drilling rig cannot operate in ice, the key factors in evaluating historical ice conditions were (1) to determine when ice was likely to arrive at the site, and (2) to determine the likely rate of advance of the ice-edge.

Published ice data available to ARCO Alaska, Incorporated for the area of interest provided observations of the ice extent on a weekly

FIGURE 1
FIRST ICE NORTH ALEUTIAN BASIN C.O.S.T. WELL SITE



and bi-weekly[2] basis for the years 1967 to 1979 and 1953 to 1981, respectively. Review of these data indicated that sea ice occurred at the site in approximately 75% of these years. The probable distribution of the first occurrence of ice at the site for years in which ice occurred is shown in Figure 1, and the average advance of the ice-edge over a 12-day interval during December and January is approximately 30 nautical miles with extreme advances of 100 nautical miles possible.

The review of published data also indicated that it would be advisable to obtain a historical data base of daily ice observations (as opposed to the weekly and bi-weekly observations included in the previously available data bases). Thus, a contract for the review of all available TIROS and NOAA satellite imagery for the area was issued. This review consisted of obtaining all imagery for the freeze-up period (December to February) for the years 1974 to 1982. For each day that the ice-edge was not obscured by clouds, a map of the ice-edge position was drawn.

Review of the satellite imagery showed the area was cloud-covered between 75 and 80 percent of the time during December and January and approximately 60 percent of the time during February. Further, clouds obscured the ice-edge for periods averaging approximately one week. Though there were many gaps in the data base, the resulting atlas of ice-edge maps did provide the most complete history of ice-edge motion in the Bering Sea.

The ice-edge maps showed that sea ice, which could threaten the rig, generally came from the north to northwest. Though ice did form on the shores of Bristol Bay, ice from the north to northwest always reached the site first. Analysis of the maps substantiated the earlier work by indicating that extreme advances of 100 nautical miles in 10 to 12 days were possible.

4. ICE EDGE MOTION MODEL

To aid in determining the minimum distance from the ice-edge to the drill rig at which abandonment operations should begin, a computer-based model of the ice-edge motion was developed. Because of the complexity of the physical processes and limitations in the available data, a statistical model, based on correlation between observed ice-edge motions and environmental parameters (such as wind and ocean current) was used. The decision to pursue a statistical approach was also based on the observation that ice drifts parallel to the surface pressure isobars at a speed of about 2% of the wind speed. For example, Thorndike and Colony[3] demonstrated that a high correlation exists between wind velocity and ice motion in the Arctic Basin away from coasts.

The relationship for the model was

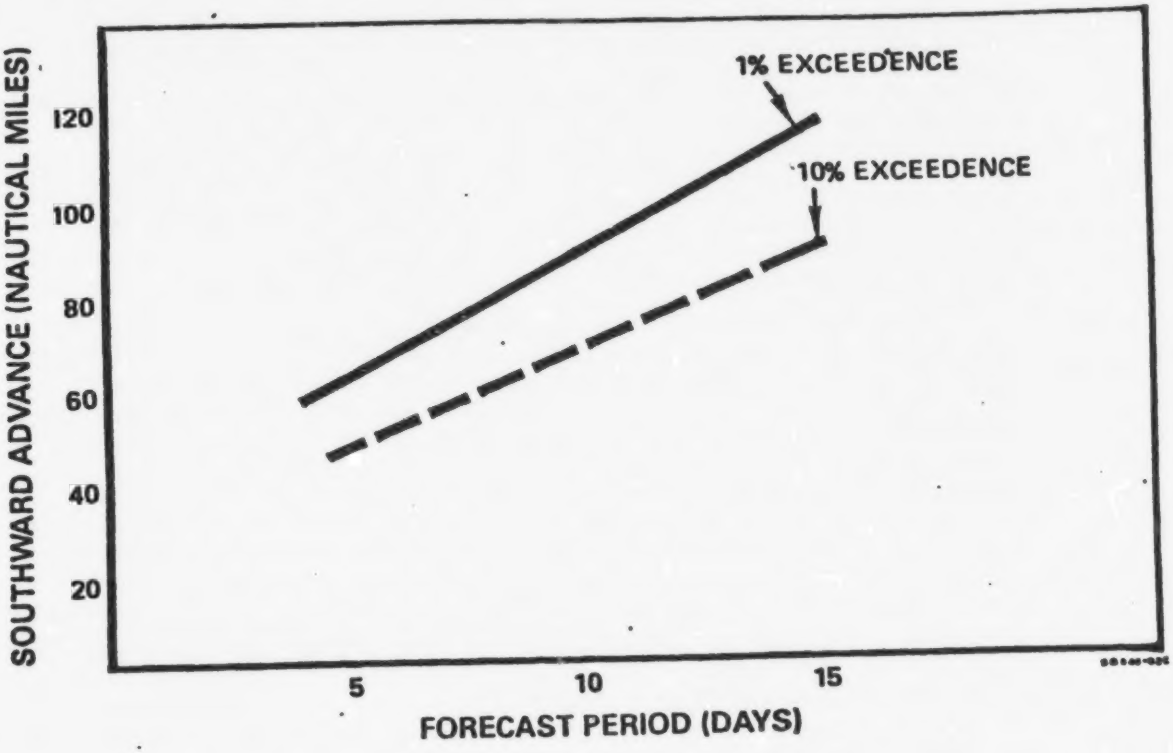
$$U_{ice} = A_o + A_1 U + A_2 x_2 + \ldots A_n x_n \qquad (1)$$

where U_{ice} is the ice velocity, U is the wind velocity, X_i are additional independent variables (e.g., current), and the coefficients $A_o, A_1, A_2 \ldots A_n$ are complex variables of the form

$$A = A_1 \exp iA_2. \qquad (2)$$

This model is a linearized version of the equation for sea ice when

FIGURE 2
ESTIMATED SOUTHWARD ICE ADVANCE FOR THE NORTH ALEUTIAN BASIN C.O.S.T. WELL SITE



the internal stress can be ignored. As discussed by Thorndike and Colony, this linear model contains essentially the same physics as the full nonlinear model.

The ice-edge data consisted of the ice-edge maps developed from the NOAA satellite imagery. It was therefore not possible to directly infer the actual position of a particular point on the ice-edge from one observation to the next. To perform regressions on the data, it was necessary to determine both the direction and the distance moved. To accomplish this, it was assumed that the ice drift was related to the wind direction by a constant turning angle.

Environmental data (consisting of wind speed and direction and current speed and direction) were available for six sites in the Bristol Bay area. Because of the sparsity of the data, it was assumed that the winds and currents from the nearest observation sites were applicable to any given point on an ice-edge.

During calculation of the regression coefficients, values of the wind (or current) over the selected observation period (i.e., 10 days) were averaged together to obtain the value used in the regression. Because the model is linear, this averaging did not affect the application of the derived coefficients to different time periods.

Using the model relationships (Equations 1 and 2) a constrained regression model was developed. A range of values of the coefficients was applied to the data, and the error in the predicted north-south location of the ice-edge was determined. The best results were produced with wind coefficients for ice speed equal to 1% of wind speed and a turning angle of 20 degrees to the right of the wind direction. The magnitude of the constant vector A_0 was 0.125 knots at 180°. For the entire data set (1974 to 1982), the variance of the extreme values represented an uncertainty of 18 nautical miles over 10 days. Using these coefficients, the advance of the ice-edge was simulated using the environmental data as the driving force. The results of this simulation are shown in Figure 2 for the 1% and 10% exceedence levels. In summary, the results showed that there was a 1% chance of the ice advance exceeding 100 nautical miles over a 12-day period.

In conjunction with the SLAR operations, the ice-edge motion model was modified for use in a forecasting mode. Forecasts for wind speed and direction (every 12 hours out to 72 hours) at five locations were input to the model. Given the initial ice-edge position (from SLAR), the model forecasts the movement of the ice-edge based on the wind forecasts. These forecasts provided ARCO Alaska with an additional margin of safety by allowing the ice-edge position to be forecast over the short term based on the actual conditions rather than just statistical estimates.

5. SLAR ICE-EDGE SURVEILLANCE

As discussed earlier, cloud cover is prevalent over the Bering Sea during the ice season. This greatly reduces the usefulness of satellites, equipped with visual and infrared sensors, for tracing the motion of the ice-edge in a continuous and reliable manner.

Further, the ceiling during cloud-covered days is generally quite low. This low ceiling effectively negates the use of light aircraft carrying ice observers.

To provide the capability for continuous ice-edge surveillance, an aircraft equipped with side looking airborne radar (SLAR) was chartered. The aircraft, a Cessna 441 Conquest (twin turbo-prop) was owned and operated by INTERA Environmental Consultants, Calgary, Canada. It was equipped with a dual Terma x-band SLAR systems. Each radar swath had a maximum width of 50 kilometers. Because of the limitations on the maximum depression angle of the radar, there was a "dead" spot (not illuminated by radar) below the aircraft equal in width to twice the aircraft altitude. SLAR operations were conducted at altitudes ranging from 25,000 to 30,000 feet.

Accurate aircraft positioning was provided by an on-board inertial navigation system. Considering the capabilities of the SLAR system and the accuracy of the aircraft navigation system, ARCO Alaska, Incorporated and INTERA jointly determined that the position of the ice-edge was mapped within 1 to 2 nautical miles.

Because this was an entirely new SLAR system, acceptance tests were scheduled prior to committing the system to operational use. Acceptance tests were completed on November 19, 1982, and operational flights began on November 22, 1982.

Sea ice during November and December 1982 was unusually light. Thus, SLAR operations were initially based at Nome, Alaska. This northern location allowed ARCO Alaska, incorporated to track the progression of the ice from the Chukchi Sea, through the Bering Straits, and into the Bering Sea. When the ice-edge reached approximately 60° North latitude (Nunivak Island), operations were moved to King Salmon, Alaska. This move occurred on December 15, 1982.

Initially, SLAR flights were scheduled for three times per week (Tuesday, Thursday, and Saturday). The Tuesday and Saturday flights were used to track the position of the ice in the Bering Straits and Norton Sound. On Thursdays, the aircraft imaged the ice from Nome to Nunivak Island to King Salmon. The aircraft and crew would then stay overnight in King Salmon and return (by the same route) to Nome on Friday. When operations were moved to King Salmon, the Tuesday and Saturday flights imaged the ice-edge from King Salmon to Nunivak Island, and the Thursday flight imaged the ice from King Salmon to Nunivak to Nome.

Within four to six hours of the completion of each flight, ARCO Alaska, Incorporated received the SLAR imagery showing the ice-edge, flight logs which showed the location of each flight track, and a map which showed the position of the ice-edge.

6. CONTINGENCY PLANNING AND DATA MANAGEMENT

6.1 Contingency Planning

Contingency planning for the North Aleutian Shelf C.O.S.T. Well was based on the following requirements:

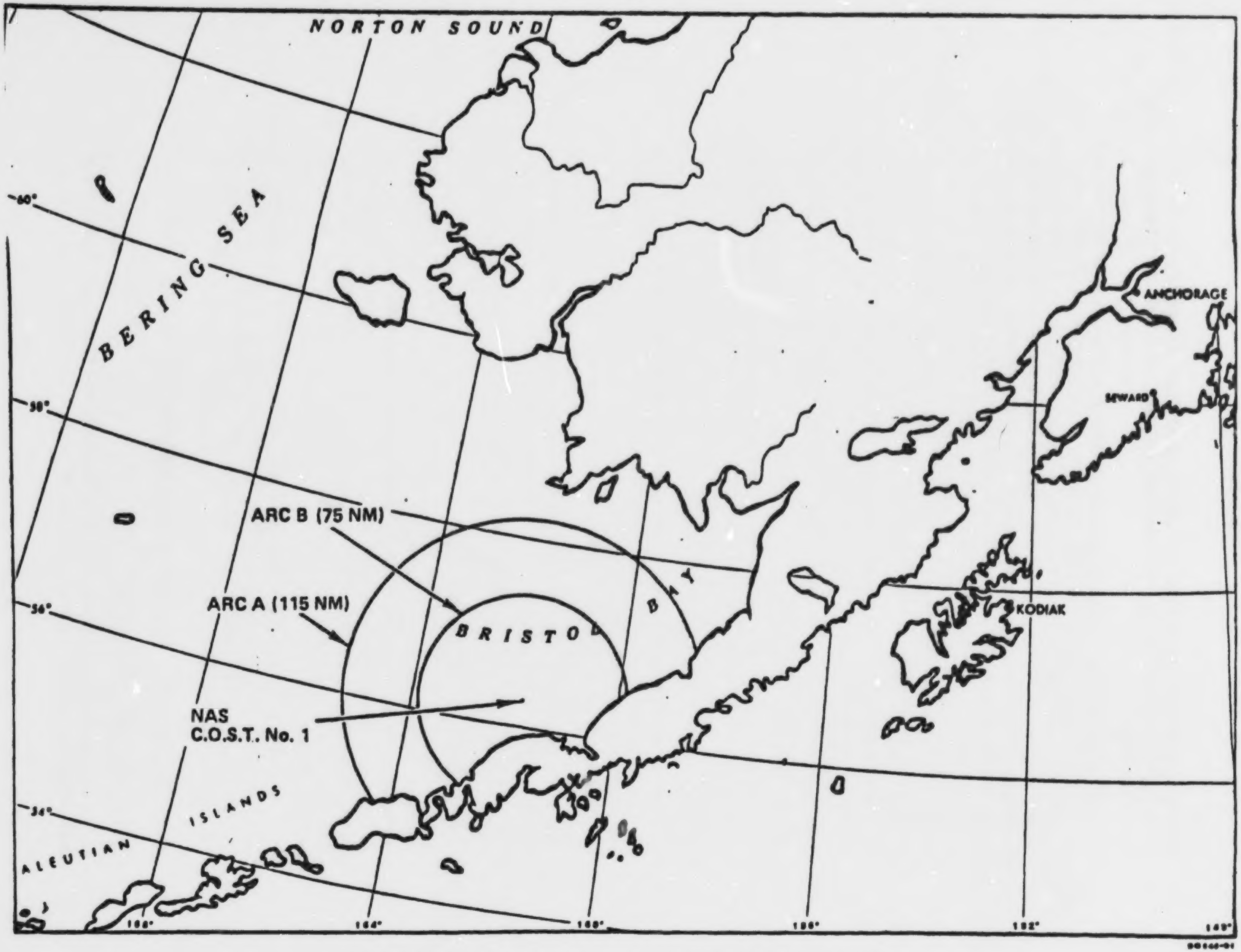

NORTON SOUND
BERING SEA
ANCHORAGE
SEWARD
KODIAK
BRISTOL BAY
ARC B (75 NM)
ARC A (115 NM)
NAS
C.O.S.T. No. 1
ALEUTIAN ISLANDS
60°
58°
56°
54°
168°
164°
160°
156°
152°
148°

FIGURE 3. ICE WARNING ZONES

1. Permanent abandonment operations, including removal of all subsea equipment, were to be completed prior to being driven offsite by ice.
2. Completion of final evaluation (coring and logging) and permanent abandonment of the well required approximately 15 days, based on a revised well depth of 18,500 ft. According to initial estimates, 10 to 12 days would have been required to abandon the well, based on a well depth of 13,500 ft.
3. All decisions relative to abandoning the well were to be based on the 99% confidence level, because of the level of risk involved and the lack of experience in operating in the Bering Sea during the ice season.

Using the results of the ice-edge modeling project, a two-phase contingency plan was developed. This plan consisted of two arcs (A&B), both centered at the well site. The radius of arc A was 115 nautical miles (1% chance of ice reaching the site in 15 days), and the radius of arc B was 75 nautical miles (1% chance of ice reaching the site in 7 days. See Figure 3). If the ice-edge crossed arc A, the following actions were to be taken:

1. Stop drilling
2. Cut 30 ft. bottom core
3. Log
4. Schedule daily SLAR ice surveillance flights

If, at the completion of logging operations, the ice-edge had not reached arc B, management could direct that normal drilling operations be started again. However, if at any time the ice-edge crossed arc B, the following actions were to be taken:

1. Stop drilling operations
2. Plug and abandon the well
3. Retrieve anchors
4. Continue daily SLAR ice surveillance flights

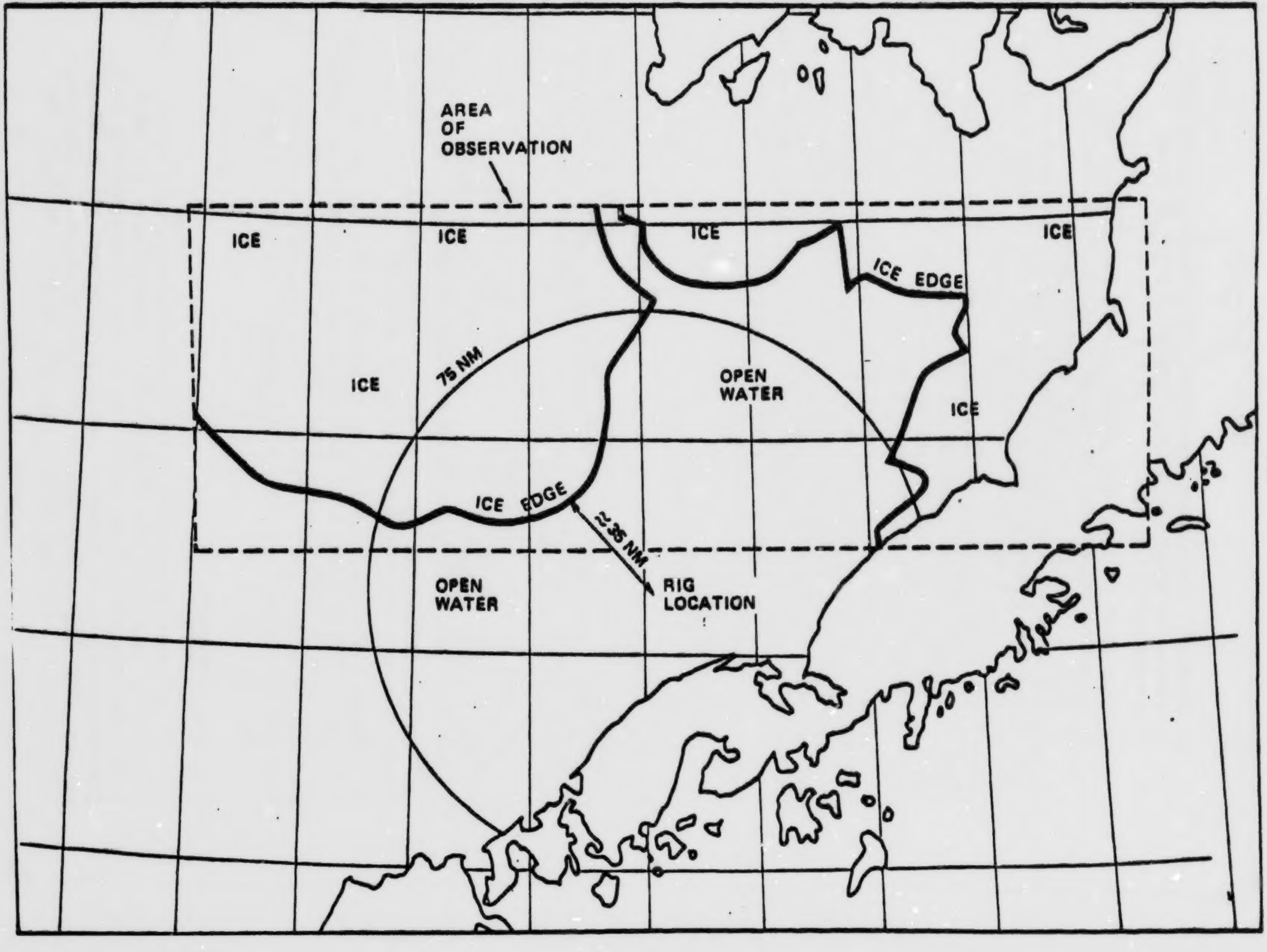
Further, should the ice cross arc B, the decision to plug and abandon the well would be automatic and irrevocable.

Though the SLAR equipped aircraft was the primary method of tracking the ice-edge position, ARCO Alaska also contracted to produce ice-edge position maps based on NOAA satellite imagery, whenever the ice-edge was not obscured by clouds. (Cloud cover was particularly heavy during December, and only five good satellite pictures were obtained.)

6.2 DATA MANAGEMENT

To implement an operational ice surveillance program, it was necessary to coordinate the results of the previous work and adopt formalized information flow paths. Formalized information flow paths provided predetermined paths of communication between all necessary parties (ARCO Alaska, Incorporated operations management in Anchorage, SLAR operations, ice-edge forecasting, and the drilling rig). The

FIGURE 4. ICE EDGE POSITION ON JANUARY 13, 1983


AREA
OF
OBSERVATION
ICE
ICE
ICE
ICE
ICE EDGE
ICE
75 NM
OPEN
WATER
ICE
ICE EDGE
≈ 35 NM
OPEN
WATER
RIG
LOCATION

information flow paths also provided a formalized decision-making process for the selection of SLAR flight plans and for the direction of drilling operations (relative to sea ice location).

One of the key requirements of the ice-edge surveillance program was to provide ice-edge position data to drilling personnel in a timely manner. This was accomplished by requiring the ice-edge maps, based on SLAR imagery, be delivered within four to six hours of the completion of each flight. Evaluation of the SLAR imagery and production of the maps were essentially accomplished manually. High quality tele-fax machines were used to transmit the finished maps from King Salmon to Anchorage.

Initial plans called for conducting the ice-edge forecasting at King Salmon, Alaska, along with the SLAR operations. However, after evaluating the potential problems of servicing the computer (Digital Equipment PDP 11/23) in a remote location and considering personnel requirements, it was decided to operate the ice forecasting model at the contractor's office in Calgary, Canada.

7. RESULTS

Drilling was terminated on January 7, 1983, with the well being drilled to 17,155 ft. This was based on operational criteria and not because of ice advancement into arc A.

At the time drilling stopped, SLAR flights were being conducted every other day in the Briston Bay - Nunivak Island area. The main Bering Sea ice-edge was being tracked into the Navarin Basin area once per week. The closest ice to the rig was 125 nautical miles away.

During the normal abandonment procedure, rapid ice advancement occurred northwest of the rig and moved into arc A and B. SLAR flights increased to every day and then twice per day to track the advancing ice-edge.

The well was permanently abandoned, anchors retrieved, and the rig towed southwest from the well location to Dutch Harbor, Alaska. During the abandonment period, the ice-edge moved to within 35 nautical miles northwest of the drilling rig (See Figure 4).

8. CONCLUSIONS

The initial C.O.S.T. Well target depth was extended from 13,500 ft. to 17,155 ft. Use of the ice-edge motion model, SLAR ice-edge surveillance, and contingency planning, allowed drilling operations to be extended and an orderly abandonment completed with an advancing ice-edge that moved to within 35 nautical miles of the drilling rig.

9. ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of S. K. Lewis, ARCO Alaska, Incorporated, D. B. Reed, W. M. Bohon, and F. J. Schuh, ARCO Oil and Gas Company, and L. Shapiro, University of Alaska (Fairbanks).

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MIZEX WEST, 1983: AN OVERVIEW OF THE REMOTE SENSING PROGRAM AND ICE CONDITIONS

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The MIZEX West Experiment took place in the Bering Sea during February, 1983. Designed as a comprehensive study documenting air-sea-ice interaction in a marginal ice zone, the program included data collection by two ships, two instrumented aircraft, and three satellites. This paper discusses the scientific objectives of the remote sensing program and includes information on aircraft instrumentation and data collection completed by the two aircraft involved: the NASA CV-990 Airborne Laboratory, and the NOAA WP-3D Research Aircraft. It also provides an overview of the ice conditions during the period as derived from ice observations and from satellite data, including NOAA 6 and 7 imagery, and Scanning Multifrequency Microwave Radiometer (SMMR) data from NIMBUS 7. It then relates the ice processes observed to previous study results, and discusses the types of analyses proposed for the remote sensing data.

1. INTRODUCTION

Recent ice investigations reflect an interest in the marginal ice zone (MIZ), an area where there is a seasonal ice edge whose position and characteristics vary considerably over time. The Bering Sea is such a region, located between the Alaskan Mainland and Siberia, extending north from the Aleutian Islands to Bering Strait (Figure 1). Several Marginal Ice Zone Experiments (MIZEX) have been conducted in this region, designed to assess air-sea-ice interactions and to provide groundtruth data for validating remote sensing information.

The MIZEX West field experiment took place during February 1983, and was designed to study advection, deformation and ablation processes occurring in the MIZ of the eastern Bering Sea (Cavalieri and Overland, 1983). A total of thirteen overflights were flown to collect mesoscale information in the area, seven with the NASA CV-990 Airborne Laboratory and six with the NOAA WP-3D Research Aircraft. The CV-990 measured ice concentrations and ice type from microwave radiance data, ice surface roughness and directional ocean swell spectra from a radar altimeter, ocean and ice surface temperature from an infrared radiometer, and recorded visual and photographic observations of the MIZ ice morphology. The P-3 measured low-level winds, heat and momentum fluxes, radiation, ice parameters from side-looking airborne radar (SLAR) and a laser altimeter, and atmospheric and oceanographic temperature profiles using dropsondes and air-droppable, expendable bathythermographs (AXBT).

Regional data collected included visual imagery from the NOAA 6 and 7 weather satellites, and passive microwave observations from the Scanning Multifrequency Microwave Radiometer (SMMR) on the NIMBUS 7 satellite. Two ships stationed in the MIZ, the NOAA R/V DISCOVERER and the USCGC WESTWIND provided local-scale groundtruth information including oceanographic and meteorological observations, deployment and tracking of a buoy array, on-ice microwave emission measurements, ice core samples, and helicopter photo reconnaissance flights.

This paper discusses the scientific objectives of the remote sensing program, then describes the general environmental conditions in

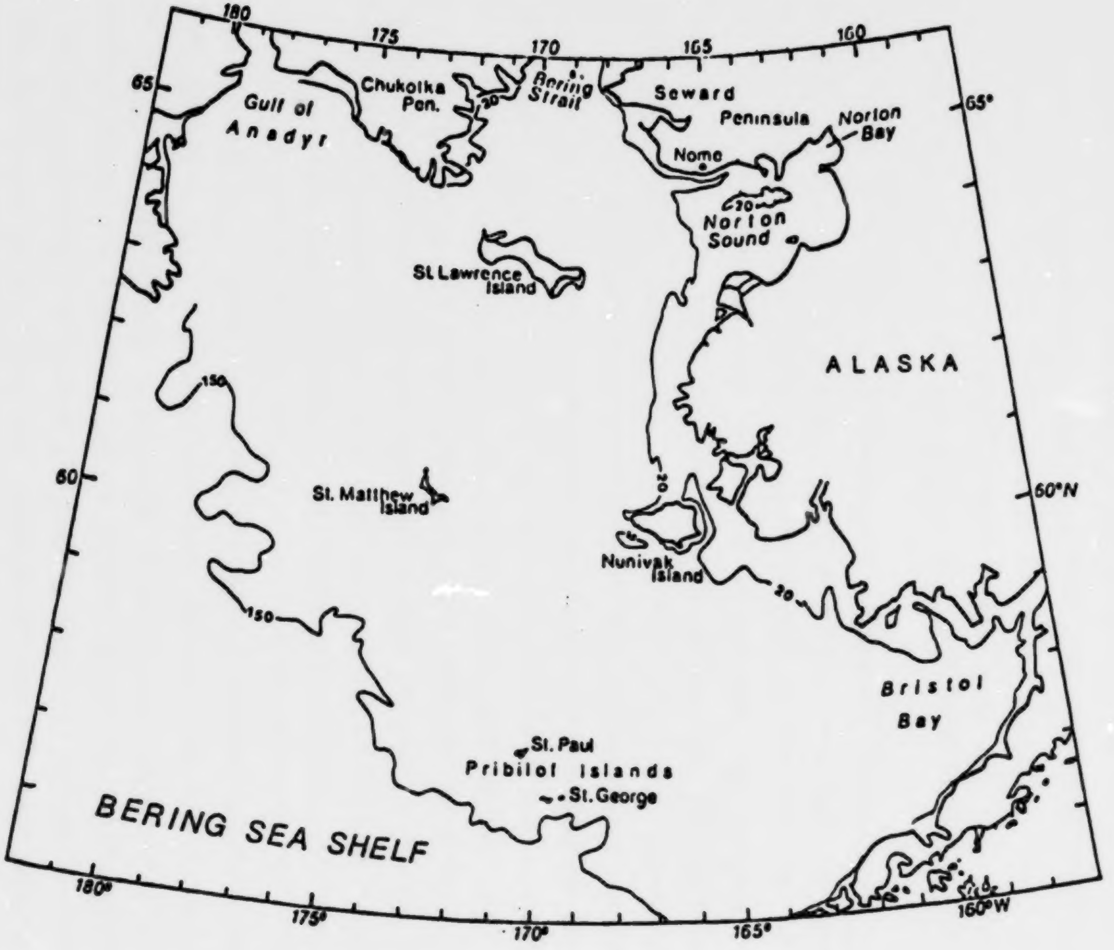

180
175
170
165
160
65
65°
60
60°N
180°
175°
170°
165°
160°W
Gulf of Anadyr
Chukotka Pen.
Bering Strait
Seward Peninsula
Norton Bay
Nome
Norton Sound
20
St. Lawrence Island
ALASKA
150
St. Matthew Island
Nunivak Island
Bristol Bay
St. Paul
Pribilof Islands
St. George
BERING SEA SHELF

FIGURE 1 LOCATION MAP SHOWING GENERAL AREA FOR MIZEX WEST 1983

the Bering Sea, and those encountered during the experiment, including satellite ice observations. The discussion then concentrates on data taken on February 10, 19 and 21, as these represent three different types of conditions in the MIZ from the beginning, middle and end of the experiment period. The descriptions relate the initial experiment results to previous studies of ice processes in the area, and include ice observations where available.

2. Scientific Objectives

The overall scientific objectives of the program included studies of the processes in the marginal ice zone designed to produce an integrated approach to understanding the air-sea-ice interactions in the region. The remote sensing studies will be used to assess the ability of the sensors to discriminate ice types using multispectral techniques. Poor visibility conditions often exist in the Bering Sea, especially near the ice edge, and these conditions preclude the use of visual reconnaissance methods for assessing ice conditions on a regional scale. The MIZEX West study will attempt to assess the limitations of poor weather conditions on the higher frequency microwave data and will include comparisons with the lower frequency, poorer resolution data available from the SMMR. The radar altimeter data will be used to evaluate altimetry, scatterometry and ranging information for polar sea ice and ocean wave studies (Cavalieri and Overland, 1983).

The processes studies will include a combination of the data taken from the regional, mesoscale and local sources. These analyses involve studies of ice edge variations resulting from wind and wave action, and changes in the pack ice cover. The mesoscale information includes documentation of changes in the windfield and boundary layer conditions across the MIZEX relative to heat flux, radiation, and surface roughness. The surface pressure charts for the area combined with aircraft observations will be used to ascertain the effects of changes in the windfield on ice divergence in the outer MIZ. Both aircraft and shipborne observations will be combined to give information on ocean temperatures south of the ice edge, and air/ice drag coefficients measured from vertical momentum flux profiles (Cavalieri and Overland, 1983).

Table 1 lists the data platforms used for the experiment and includes the ships, satellites and two aircraft involved. A complete description of all the data collected is not within the scope of this paper; questions concerning data analysis should be addressed to responsible parties. Appendix A lists the status of the MIZEX West Experimental Data as of May, 1983. Addresses for the investigators mentioned appear at the end of the listing.

3. General Overview of Environmental Conditions in the Bering Sea

In heavy ice years, the Bering Sea pack ice can reach approximately 58°N, covering the area from Bering Strait to the Pribilof Islands. All ice formed is first-year ice which melts back completely each season. A continental, arctic climate characterizes the winter months, replaced by maritime influences in the summer (Overland, 1980). In heavy ice years, fewer storms occur north of 60°N and cold air from Alaska and the Arctic produces dominant winds from the N-NE. Generally, more storms occur in light ice years, propagating up the Siberian side bringing more winds from the S-SW (Overland and Pease, 1982). The 1982-83 ice season appears to have been a slightly higher than average ice year.

Maximum extent of the ice occurs in late February to late April changing to spring meltback in March to June (McNutt, 1983). By late June, the Bering Sea is ice-free to the Strait (Webster, 1981). The ice advances to the S-SW under N-NE wind conditions forming polynyas on the leeward side of east-west trending coasts. Polynyas occur seasonally to the south of the coast near Nome, south of St. Lawrence Island, and south of Nunivak and St. Matthew Islands as the ice reaches maximum extent.

TABLE 1

MIZEX DATA COLLECTION

PLATFORM	SENSOR	TYPE OF DATA	COMMENTS
DISCOVERER	Shipboard	CTD, SST, SAT, radiosondes met obs, wave information, ice observations	Obtain information from Dr. J. Schumacher, NOAA/PMEL
WESTWIND	Shipboard	CTD, SST, SAT, radiosondes, met obs, wave info., ice observations	Obtain through Dr. Seelye Martin, UW
	Buoy Array	ARGOS buoy positions	From Carol Pease, NOAA/PMEL
		Radar telemetry buoys	Dr. Seelye Martin, UW
		Unmanned met stations; windspeed/dir., air temp., water currents	Carol Pease, NOAA/PMEL
NOAA 6	AVHRR	Imagery	Operated well during exper.
NOAA 7	AVHRR7	Imagery	Operated well during exper.
NIMBUS 7	SMMR	Plots of ice concentration	Avail. through AES, Ottawa
		Raw data tapes	Obtain from NASA/GODDARD

TABLE 1 (Cont'd)

MIZEX DATA COLLECTION (Aircraft)

PLATFORM	SENSOR	TYPE OF DATA	COMMENTS
P3	SLAR APD 7	Contact copies - negatives	Worked well except 3-22-83
	LASER	Geodolite 3A - strip chart	Obtain from AOML
	Gust Probe	Digital tapes	Obtain through NOAA/PMEL
	Radiation	Pyrgeometer (3.5-5.0 m) - digital tape	All worked well
		Pyranometer (.68-2.8 m) - digital tape	Calibrated by K. Katsaros, UW
		Pyranometer (.30-2.8 m) - digital tape	Obtain from UW
		Radiometer PRT5 (8-15) - digital tape	
	Cameras	16 mm print copies Two side-looking One nose camera One down-looking	Obtain through NOAA/PMEL
	Dropwindsonde	Digital tape	Obtain through NOAA/PMEL
	Flight level data	Printout and computer tape	Obtain through NOAA/PMEL
CV990	Radiometers (ESMR)	19.35 GHz imagery; tapes	Worked well throughout mission; available from NASA/GODDARD
	(RMR)	19.35 GHz high resolution imagery	Did not operate
	(MFR1)	10.7 GHz, 18.0 GHz, 21.0 GHz, 37.0 GhZ - data tapes	Obtain from NASA/GODDARD All functioned well
	(MFR2)	21.0 GHz (up); 37 GHz (up) - data tapes for Atmos. corrections	All functioned well Obtain through NASA/GODDARD
	(HFPMI)	92.0 GHz 183 GHz - imagery and data tapes	Functioned well except 19 February Obtain through NASA/GODDARD
	Radar Altimeter	Altimeter mode - tapes Scatterometer mode - tapes	Some difficulty at high alt. Obtain from RAL
	Radiation	PRT5 - 10.7 m - tapes	Obtain from NASA/Ames
	Camera	K587 - 5 in. format (nadir) - prints	Worked well except 22 Feb.
		K587 - 5 in. format (45°R) - prints	Obtain from NASA/Ames

The grease ice generated in these polynyas thickens downwind, congeals to form floes and migrates southward at approximately 28-40° to the right of the wind direction (Loschilov, 1974; Muench and Ahlnas, 1976; McNutt, 1980, 1981). Although these conditions dominate during February to March, occasional storms from the S-SW or S-SE close the pack ice, fill the polynyas and push the floes northward. At the ice edge, the ice cover interacts with the incoming swell, breaking into smaller floes and forming ice bands which migrate downwind faster than the interior pack ice (Martin et al, 1983). As this ice encounters warmer water, it melts, and the location of this warmer water determines the ice edge limit throughout the season (Pease, 1980). During ice advance, the pack may turn over from two to five times (Pease, 1980).

The character of the ice edge is important in understanding the radiometric signature of ice found in this area. The ocean swell fractures ice advected from the interior pack. This ice consists of thick and thin white ice as well as grey-white and grey ice formed in between the advancing thicker ice as it spreads out downwind to the wider, southern end of the basin. At the edge, the ice breaks into small rough floes which measure 10-20 m across and raft to 1-5 m thick (Bauer and Martin, 1980; Squire and Moore, 1981; Martin et al, 1983). These floes move to open water under off-ice winds forming bands typically 1-10 km in length and 0.1-1 km wide (Muench and Charnell, 1977), oriented at approximately right angles to the wind. Generally, ice at the edge consists of three zones (Bauer and Martin, 1980): the edge zone, 5-10 km wide consisting of small, broken floes; the transition zone, 5 km wide with small, rectangular floes; and the interior zone 100 km in extent with large floes (Figure 2). The widths of the zones vary depending on the intensity of the incoming swell and its ability to fracture the ice. These conditions were present in the March, 1979 MIZEX study. Off-ice winds produce a diffuse edge with many ice bands which move downwind and ablate; on-ice winds compact the floes at the edge, but generally bring increased swell activity, fracturing the ice further into the pack while pushing floes against each other. Generally, melt and decay of the ice characterizes the region at the edge, but the onset of cold conditions can cause refreezing of the surface layers of the water and the ice.

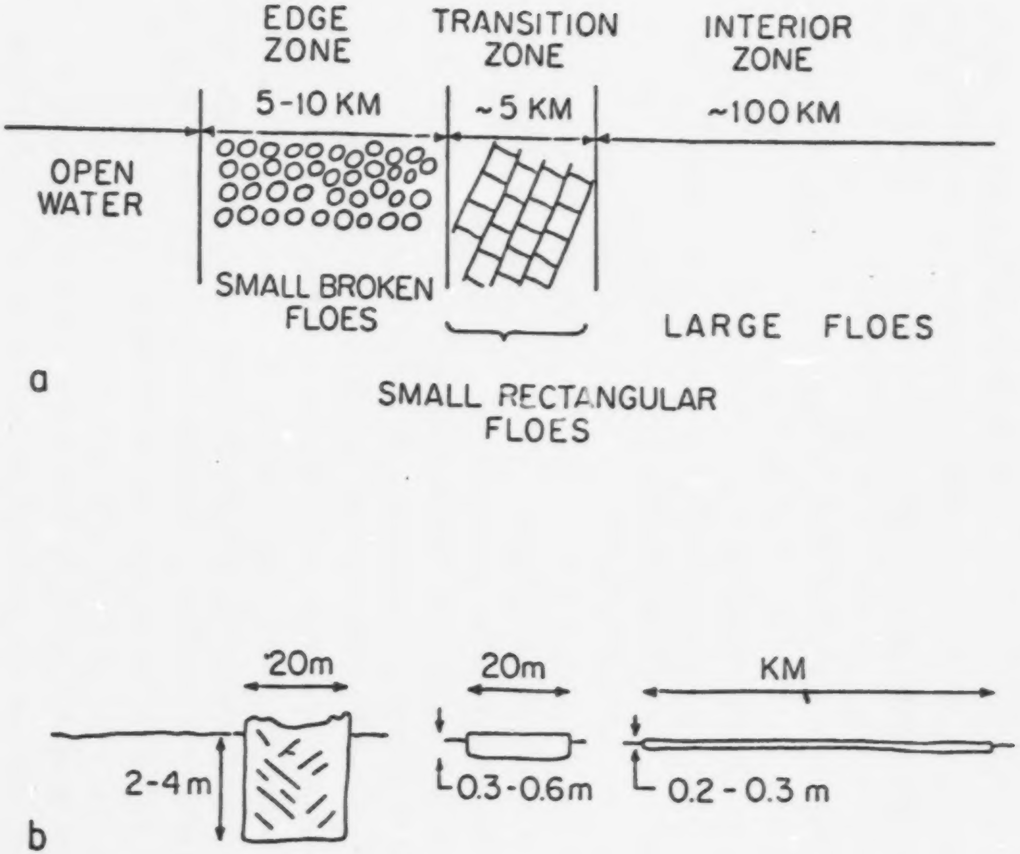

EDGE ZONE
TRANSITION ZONE
INTERIOR ZONE
5-10 KM
~5 KM
~100 KM
OPEN WATER
SMALL BROKEN FLOES
LARGE FLOES
a
SMALL RECTANGULAR FLOES
20m
20m
KM
2-4 m
0.3-0.6m
0.2 - 0.3 m
b

FIGURE 2 SCHEMATIC DIAGRAM OF FLOE SIZES FOUND ALONG THE ICE EDGE DURING MIZEX, 1979: (a) Planimetric view, (b) Cross-section (From: Bauer and Martin, 1980).

Ice retreat begins when warmer air arrives from the south and combines with the seasonal increase in solar insolation. The edge migrates northward, ice production stops in the southerly polynyas and they close as new polynyas open to the north, or leeward side, of the coasts, especially St. Lawrence Island and southern and eastern Norton Sound. The ice generally moves northward, however, temporary reversals of this motion are not uncommon.

4. CONDITIONS DURING MIZEX WEST, 1983

The aircraft portion of the experiment period occurred between February 10 and 23, 1983. At the beginning of the month, the winds blew from the SE and created heavy cloud cover over the area. These cloudy conditions continued as the winds gradually shifted to the east, and the area began to become cloud-free by February 12. By February 13, the winds shifted to the NE and cloud-free conditions existed until February 22. The clear skies generated by the NE winds created ideal conditions for combining satellite, aircraft and shipborne data to assess ice conditions in the region.

At the beginning of the experiment, the ice moved westward along the ice edge due to motion created by easterly winds. During this period the position of the ice edge did not change significantly. While easterly winds blew along the ice edge, NE winds near St. Lawrence Island kept the polynya open on the leeward, or southern side. As the ice in this area continued to migrate downwind, a shear zone developed in the pack ice south of the island. When the winds gradully changed to northeasterly over the entire basin, all the pack ice began to move downwind. The ice edge advanced steadily during this period, polynyas developed south of St. Lawrence, St. Matthew and Nunivak Islands, and the ice edge became diffuse and contained bands and streamers. The ice edge advanced over 45 nm in the eastern Bering Sea during this period, and extended almost to the Pribilof Islands.

During the experiment, a buoy array placed on the ice tracked ice motion while measuring meteorological conditions at two of the fourteen stations. Figure 3 illustrates the eight ARGOS buoy placements and shows their positions plotted throughout the experiment. The buoys were initially expected to head toward the S-SW and exit into the ice edge east of St. Matthew Island. The easterly winds moved the ice toward the west, north of St. Matthew Island. When the winds shifted to the NE, the buoys moved to the S-SW and exited to the ice edge west of St. Matthew Island. This change in the expected motion of the buoy array meant that flight plans had to be altered to accommodate the greater distance involved in reaching the study area. The buoy positions, attended by the USCGC WESTWIND, provided valuable information on ice motion and velocities, and demonstrated that the ice velocities increased as the floes entered the diffuse ice edge.

The visual NOAA satellite imagery provided a good regional record of ice conditions during cloud-free periods. The experiment also used the first application of real-time analyses of the satellite SMMR data for planning missions based on algorithm-derived ice concentration charts. A combination of these two types of satellite data products showed that on February 11 the ice edge was located at approximately 58°37' along 168°W. By February 20 the edge moved to 57°54', a distance of 86.9 km (45.2 nm). During the same period the ice edge position west of St. Matthew Island along 174°W changed from 60°29' to 60°24', a difference of only 10.1 km (5.2 nm). The buoy array indicated that the ice continued to move southward during this period, and in this case ice melt rates in the western Bering Sea seemed to exceed those in the eastern Bering Sea. The sea surface temperature (SST) analyses produced using SMMR data show little relative motion in the + 2°C isotherm in the western Bering Sea, but a southerly migration in the eastern Bering Sea during the same period.

The following three subsections describe conditions found during three specific aircraft flight dates: February 10, 19, and 21. The February 10 data came from the CV-990, and were obtained during cloudy conditions and on-ice winds (Cavalieri and Gloersen, 1983). On the second date, February 19, both aircraft flew with the CV-990 documenting changes in the ice cover from a mosaic pattern flown at the ice edge, and the P-3 providing information between the two ship positions from within the pack ice

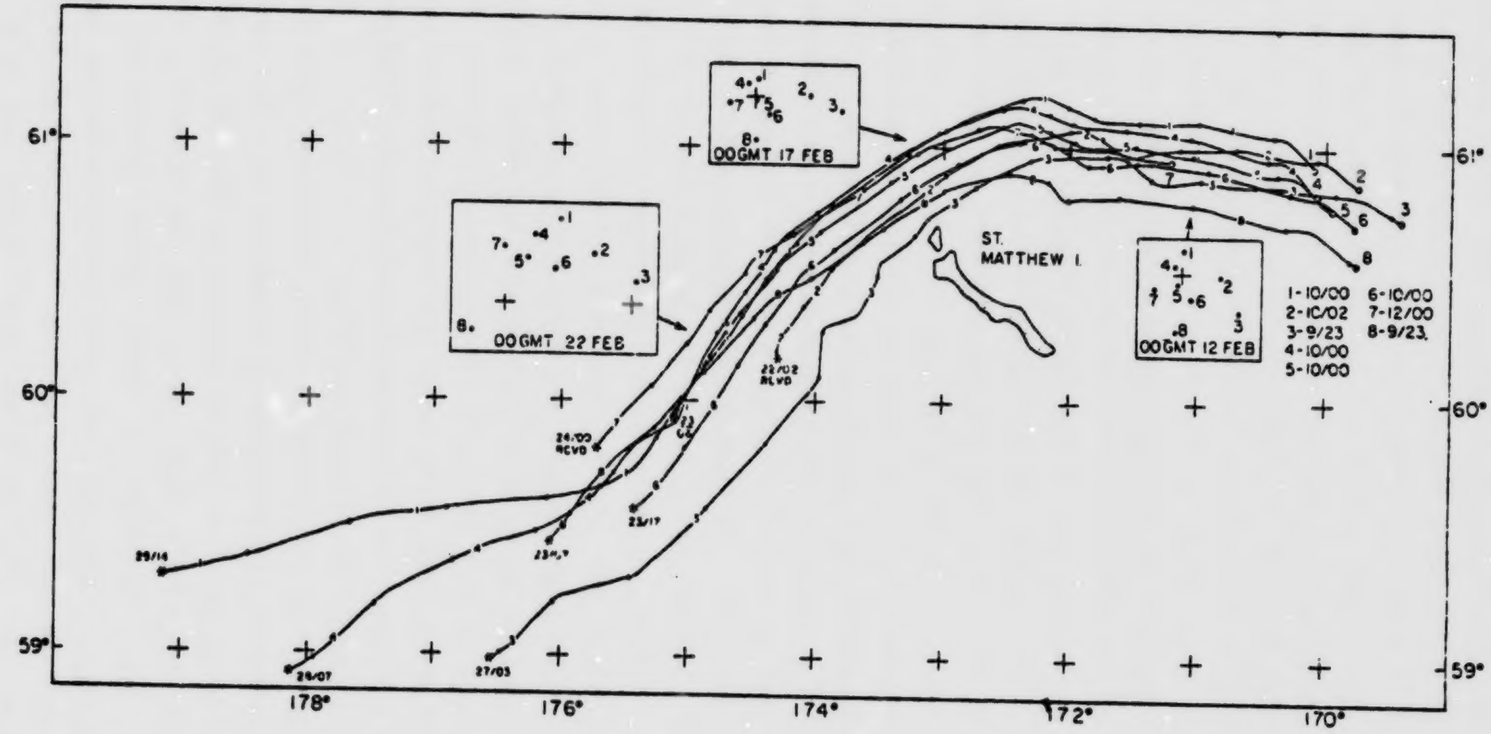

61°
60°
59°
178°
176°
174°
172°
170°
ST. MATTHEW I.
OOGMT 22 FEB
OOGMT 17 FEB
OOGMT 12 FEB
1-10/00
2-10/02
3-9/23
4-10/00
5-10/00
6-10/00
7-12/00
8-9/23
29/14
28/07
27/03
24/00 RCVD
23/17
22/02 RCVD

FIGURE 3 PLOT OF ARGOS BUOY POSITIONS DURING THE MIZEX WEST EXPERIMENT. THE BUOYS WERE EXPECTED TO HEAD S-SW AND EXIT EAST OF ST. MATTHEW ISLAND (Source: C.H. Pease, Marine Meteorological Services, NOAA/PMEL, Seattle, Washington)

to the ice edge. On February 21, the P-3 flew a pattern designed to study cloud streets at the ice edge (Overland and Pease, 1983). On the same day, the CV-990 flew a pattern designed to mosaic ice conditions around St. Matthew Island into Navarin Basin. The first flight, February 10, occurred during SE winds and extensive cloud cover; the second after NE winds occurred over the region; the last after NE winds had created well-developed off-ice conditions in the pack ice and along the ice edge. Table 2 summarizes the flight days for each aircraft.

3.1 February 10, 1983

Figure 4 illustrates the SMMR ice concentrations for February 10 as sent to the two research vessels. Cloud cover precluded the use of NOAA satellite imagery for documenting ice conditions, so flight plans were based on the SMMR analysis provided by Atmospheric Environment Services, Canada. Figure 5 shows the analysis prepared by NASA Goddard also derived from SMMR data, but using a different algorithm. Only the CV-990 flew on this day, as illustrated in Figure 6. Figures 7 and 8 show the ESMR and HFMI imagery obtained during the overflight. They indicate that the ice edge was fairly compact with some open water/new ice evident in polynyas within the pack ice, and small streamers along the ice edge oriented N-S.

3.2 February 19, 1983

By February 19, N-NE winds had developed over the entire region and NOAA imagery was available for assessing ice conditions. The imagery showed ice bridging through Bering Strait, polynyas on the leeward sides of all the islands and well developed, diffuse ice edge conditions with bands oriented roughly NW to SE. Two other interesting features also appeared; a grounded floeberg north of Nunivak Island, and a long lead in the ice reaching from St. Matthew Island to Nunivak Island.

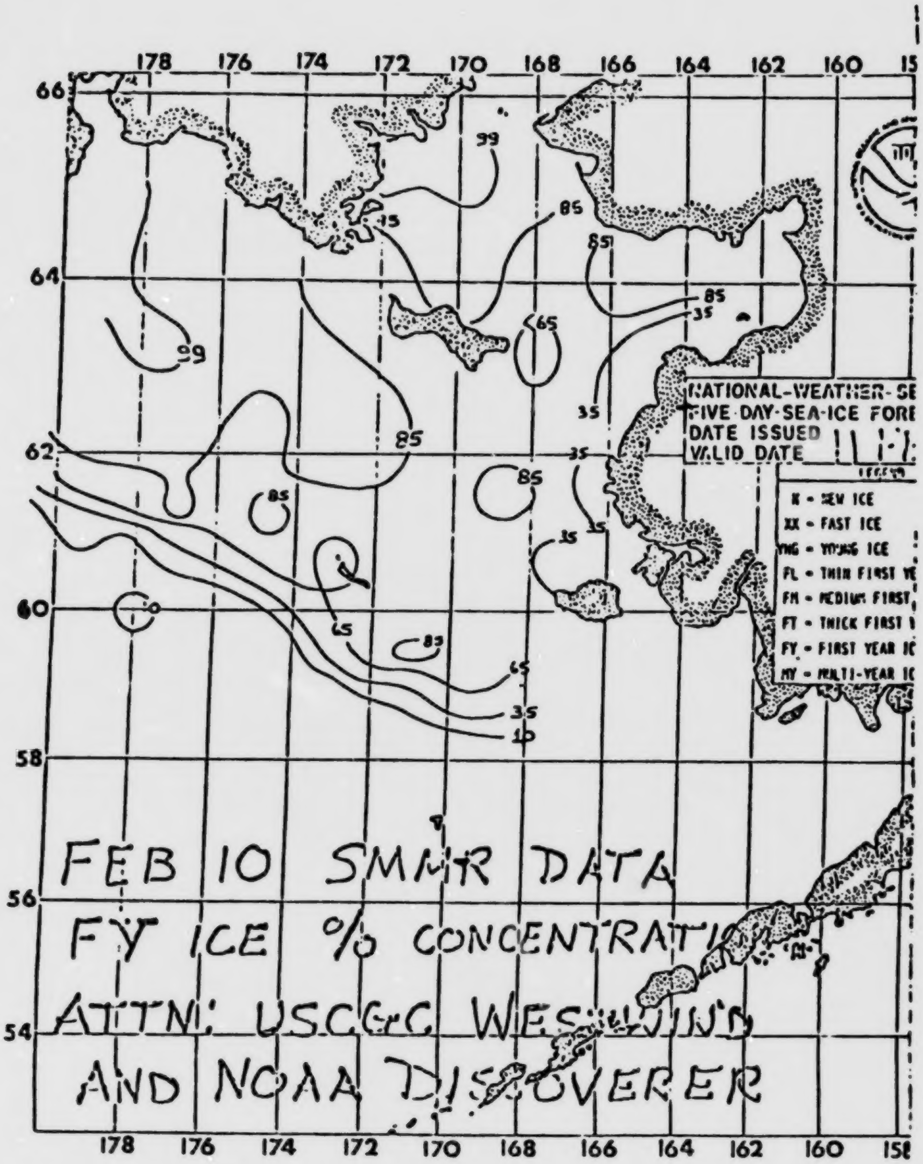
The floeberg was visible due to its polynya which appeared and changed orientation relative to the local wind. NOAA

TABLE 2

FLIGHT DAYS FOR NOAA P-3 AND NASA CV-990 DURING MIZEX WEST 1983

<table>
<tr><th colspan="2">NOAA P-3</th></tr>
<tr><td>13 February</td><td>DELTA Pattern - drag coefficient stack over the WESTWIND (61.0°N, 171.9°W)</td></tr>
<tr><td>16 February</td><td>NOVEMBER Pattern - to investigate the ice edge as found between the two ship positions</td></tr>
<tr><td>18 February</td><td>St. Lawrence Polynya flight</td></tr>
<tr><td>19 February</td><td>NOVEMBER Pattern - to investigate the ice edge as found between the two ship positions</td></tr>
<tr><td>21 February</td><td>CHARLIE Pattern - to document cloud streets along the ice edge</td></tr>
<tr><td>23 February</td><td>SIERRA Pattern - to investigate the effects of southerly winds along the ice edge</td></tr>
<tr><th colspan="2">NASA CV-990</th></tr>
<tr><td>10 February</td><td>MODIFIED ALPHA - mosaic of ice edge conditions</td></tr>
<tr><td>12 February</td><td>MODIFIED ALPHA - mosaic of ice edge conditions</td></tr>
<tr><td>13 February</td><td>St. Lawrence Island polynya flight modified to include Norton Sound</td></tr>
<tr><td>18 February</td><td>St. Lawrence Island polynya flight</td></tr>
<tr><td>19 February</td><td>ALPHA PATTERN - mosaic of ice edge conditions</td></tr>
<tr><td>21 February</td><td>MODIFIED ALPHA - mosaic of ice conditions near St. Matthew Island into Navarin Basin</td></tr>
</table>

Sources: Cavalieri, D. and Gloersen, P., 1983.
Overland, J.E. and Pease, C.H., 1983.


178
176
174
172
170
168
166
164
162
160
66
64
62
60
58
56
54
99
35
85
85
85
35
65
99
35
85
35
85
85
35
35
65
83
65
35
10
NATIONAL-WEATHER-SE
FIVE-DAY-SEA-ICE FORE
DATE ISSUED
VALID DATE
N = NEW ICE
XX = FAST ICE
YNG = YOUNG ICE
FL = THIN FIRST YE
FM = MEDIUM FIRST
FT = THICK FIRST
FY = FIRST YEAR IC
MY = MULTI-YEAR IC

FEB 10 SMMR DATA
FY ICE % CONCENTRATI
ATTN: USCGC WESTWIND
AND NOAA DISCOVERER

FIGURE 4 SMMR DATA FOR 10 FEBRUARY, 1983 SHOWING ESTIMATED ICE CONCENTRATIONS. THE ORIGINAL DATA WAS SENT BY ATMOSPHERIC ENVIRONMENT SERVICE, CANADA TO THE NATIONAL WEATHER SERVICE IN ANCHORAGE WHERE IT WAS TRANSCRIBED AND DATAFAXED TO THE SHIPS FOR OPERATIONAL PLANNING

(Source: Bruce Webster, NWS, Anchorage, Alaska)

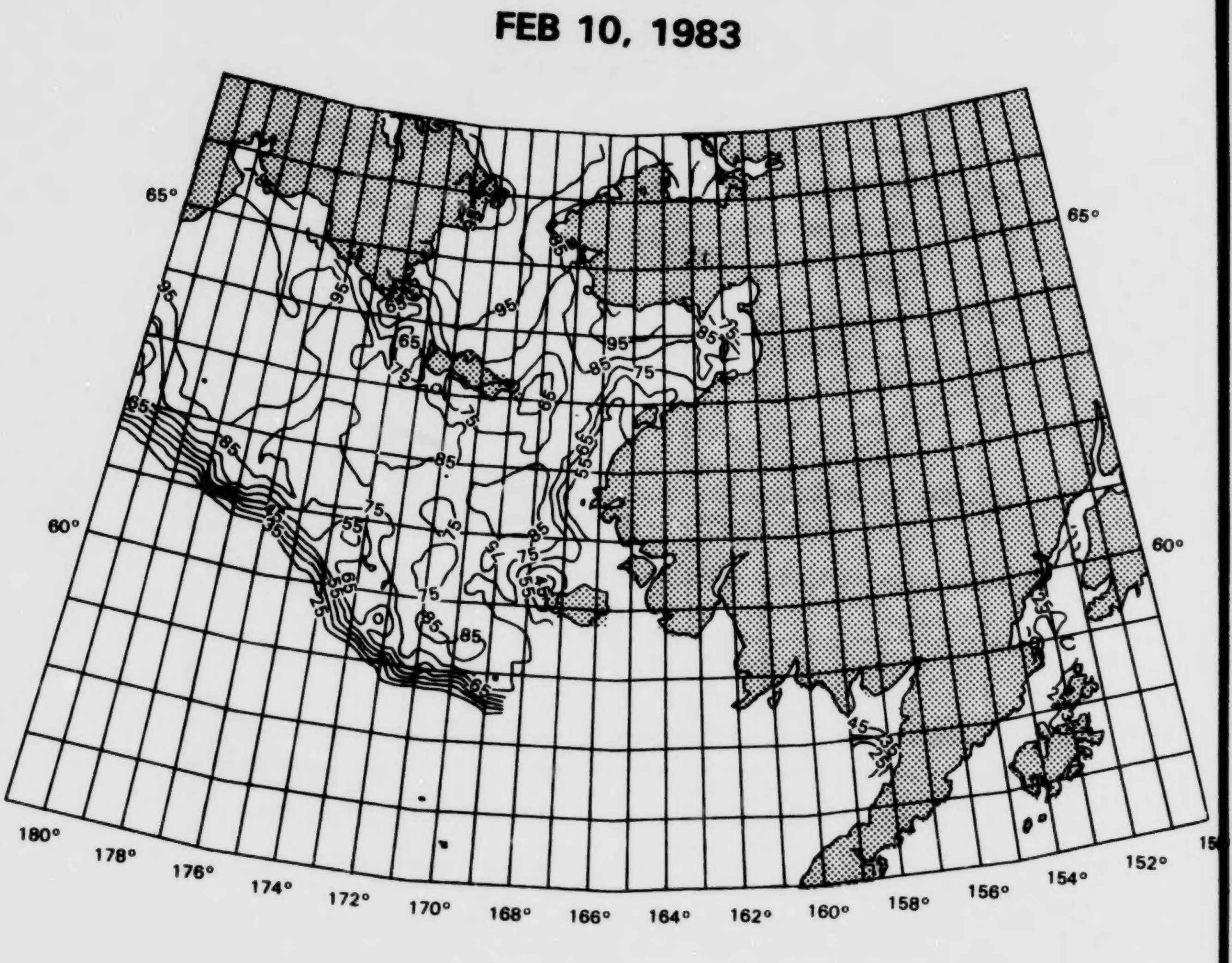
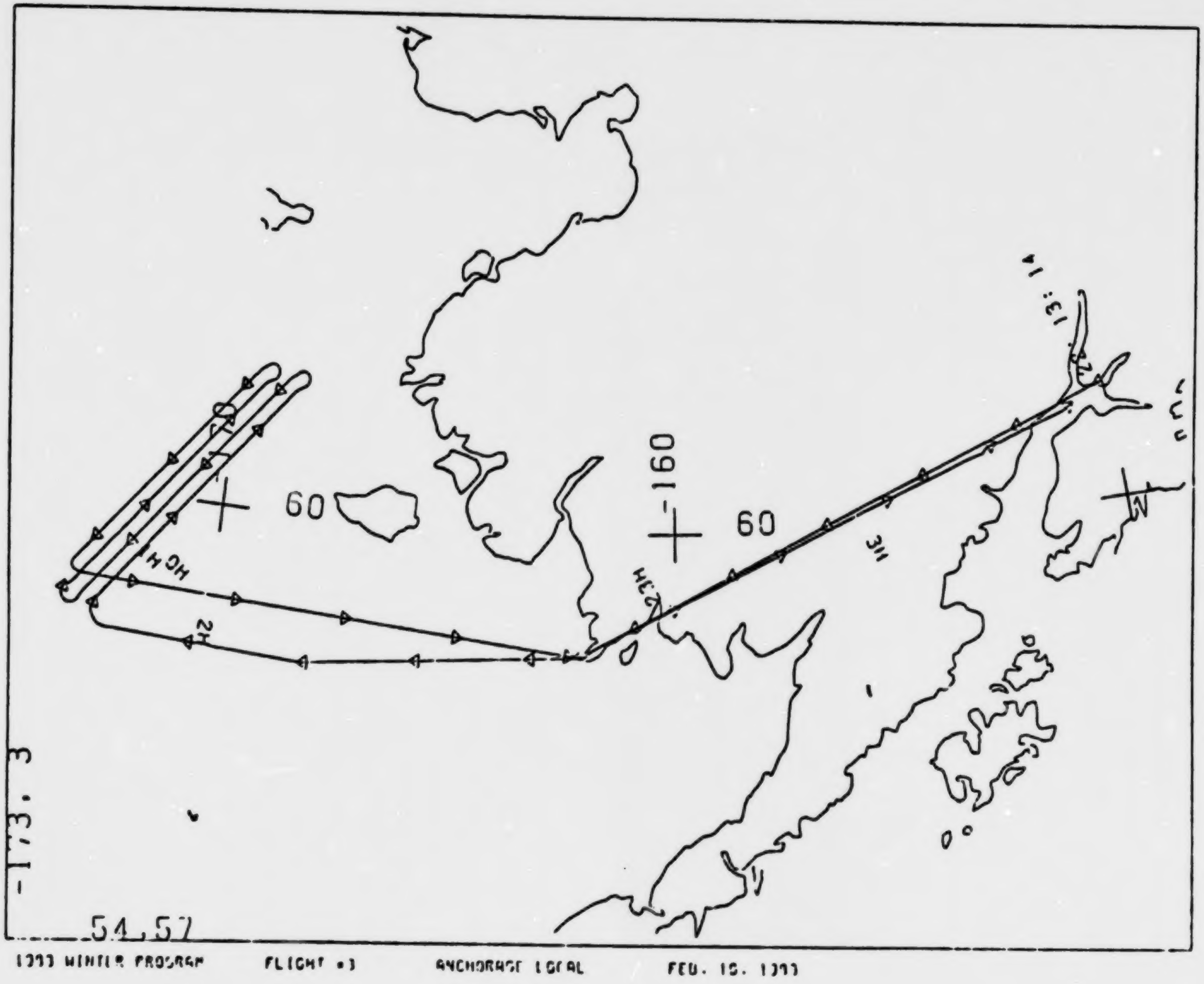

FEB 10, 1983
65°
65°
60°
60°
180°
178°
176°
174°
172°
170°
168°
166°
164°
162°
160°
158°
156°
154°
152°
95
95
95
95
65
65
75
75
75
75
85
85
85
85
85
85
65
55
55
45
35
25
75

FIGURE 5 SMMR ICE CONCENTRATIONS FOR 10 FEBRUARY 1983 DERIVED WITH THE NASA/GODDARD ALGORITHM



-173. 3
54.57
60
60
-160
2H
HOH
H23
3H
22. 13: 14
1983 WINTER PROGRAM
FLIGHT #3
ANCHORAGE LOCAL
FEB. 10. 1983

FIGURE 6 FLIGHT FOR CV-990, 10 FEBRUARY 1983, SHOWING MOSAIC PATTERN NEAR ST. MATTHEW ISLAND

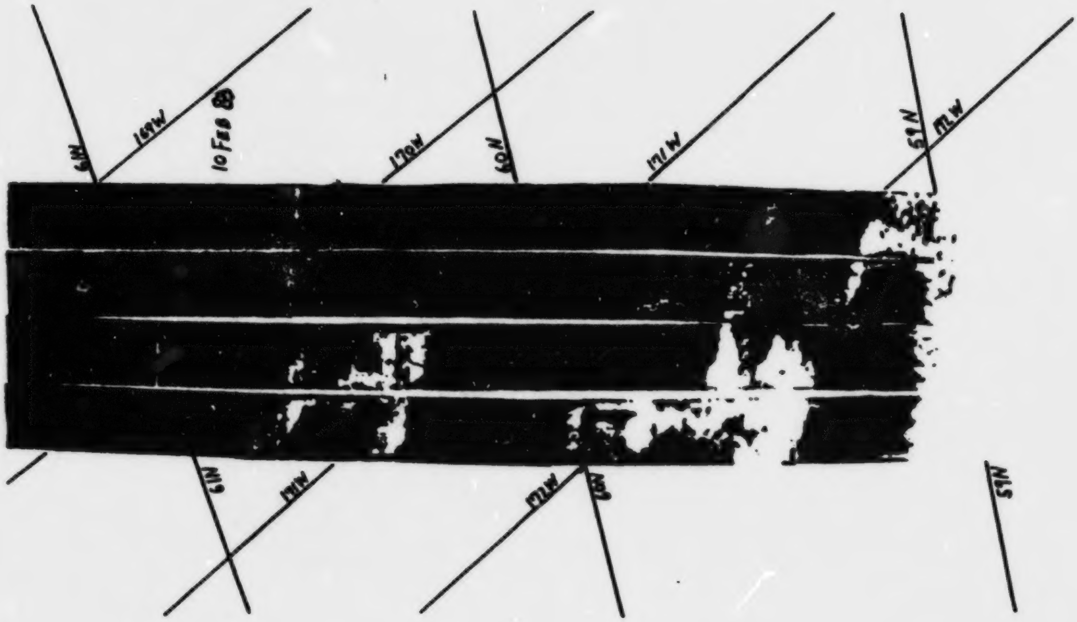

61N
169W
10 FEB
170W
60N
171W
59N
172W
61N
171W
172W
60N
59N

FIGURE 7 MOSAIC OF ESMR IMAGERY RECORDED ONBOARD THE NASA CV-990 AIRCRAFT. NO CORRECTIONS HAVE BEEN MADE FOR IMAGE DISTORTION

navigational charts indicate a shoal in that area in approximately 6 fathoms of water (10.9 m). This implies that this ice had a keel of at least 10.9 m, larger than expected in the Southern Bering Sea. Ridges measured north of St. Matthew Island were 1.2-1.8 m (4-6 ft.) on average, with approximately 10% of the samples 3.3 m (10 ft.) or greater. This ice was 60-80% ridged and indicates a source of heavily ridged ice which could enter Navarin Basin.

The long lead stretching from St. Matthew Island to Nunivak Island first appeared on February 18 NOAA imagery. It continued to migrate toward the ice edge as a recognizable feature until at least February 21. After that date the area again became cloud-covered. Figure 9 illustrates this migration relative to the ice edge position, and comparisons with the buoy data indicate that although the edge in the eastern Bering Sea appeared to advance more rapidly, actual ice velocities in the two areas were very similar, substantiating the idea that ice melt in the western Bering proceeds more rapidly.

Figures 10 and 11 illustrate the flightlines for the NOAA P-3, and the NASA CV-990, respectively, for February 19, 1983. The P-3 flew from the USCGC WESTWIND at 60°51'N; 174°50'W to the DISCOVERER at 59°83'N; 175°43'W at several different altitudes to collect meteorological information, and at a lower altitude, to obtain SLAR imagery of the area from the WESTWIND to the DISCOVERER and downwind 60 km (37.2 mi). The SLAR swath width is approximately 3 mi on each side, and the resolution is approximately 8 m. The CV-990 flew over the ice completing a six-leg mosaic over St. Matthew Island and into the Navarin Basin. The data documented changing ice conditions in the ice generation area-lead pictured in Figure 9. The P-3 low-level flights were coincident with the higher altitude CV-990 runs. Analysis has begun on this data set.

3.3 February 21, 1983

On February 21, the NOAA P-3 flew a pattern designed to collect information on the cloud streets, or long, linear roll

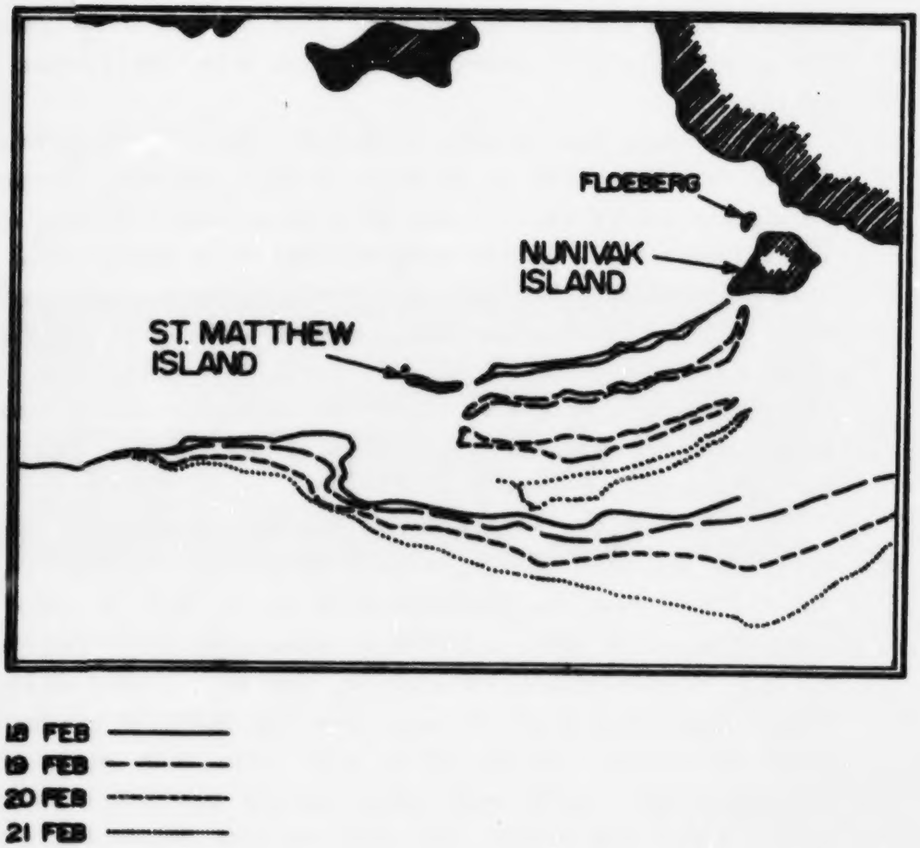

FLOEBERG
NUNIVAK ISLAND
ST. MATTHEW ISLAND
18 FEB
19 FEB
20 FEB
21 FEB

FIGURE 9 MIGRATION OF LONG, LINEAR LEAD WHICH STRETCHED BETWEEN ST. MATTHEW AND NUNIVAK ISLANDS. THIS ANALYSIS FROM NOAA IMAGERY SHOWS THE LEAD MOVING SOUTHWARD WITH THE ICE EDGE IN THE EAST, BUT WITH A RELATIVELY STATIONARY EDGE IN THE WEST. BUOY POSITIONS FOR THE WESTERN EDGE INDICATED ICE VELOCITIES SIMILAR TO THE EASTERN EDGE.

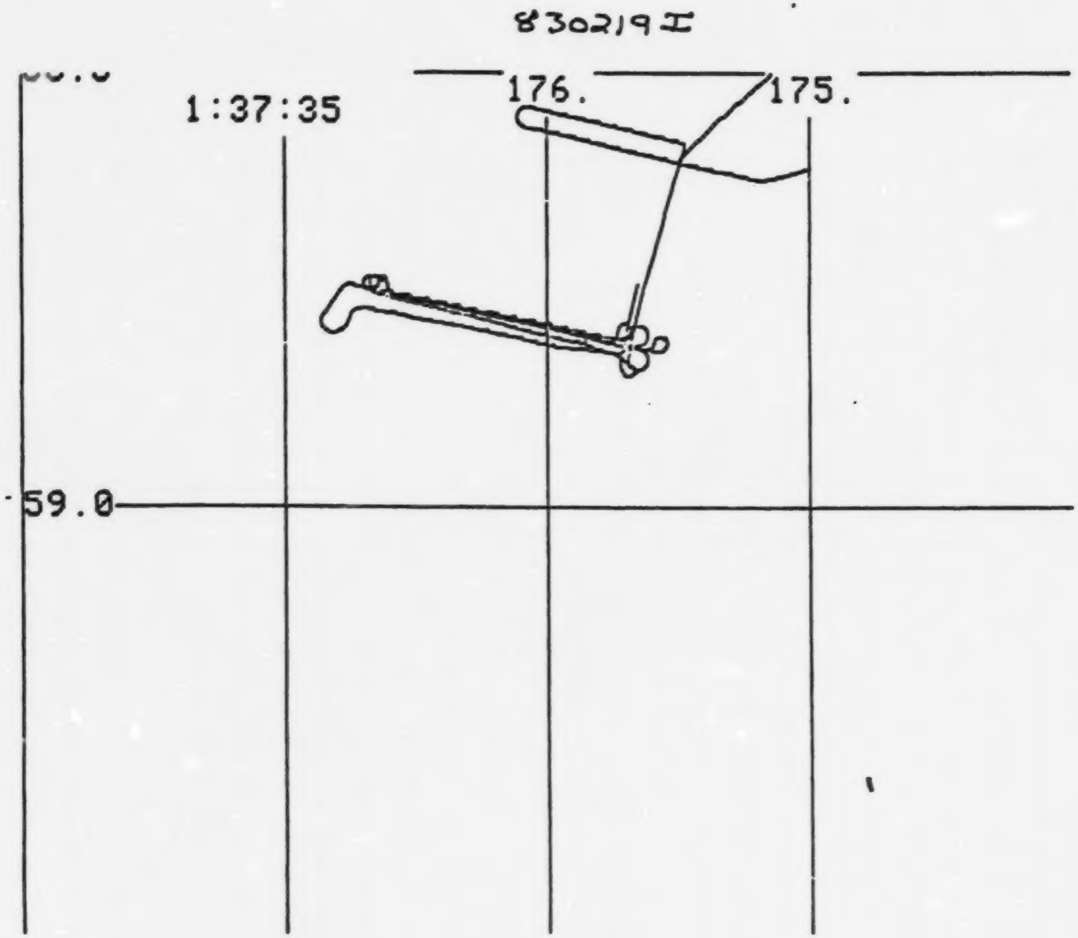

830219 I
1:37:35
176.
175.
59.0

FIGURE 10 PORTION OF NOAA P-3 FLIGHTLINE FOR 19 FEBRUARY 1983, SHOWING STACK PATTERN FLOWN TO COLLECT METEOROLOGICAL INFORMATION

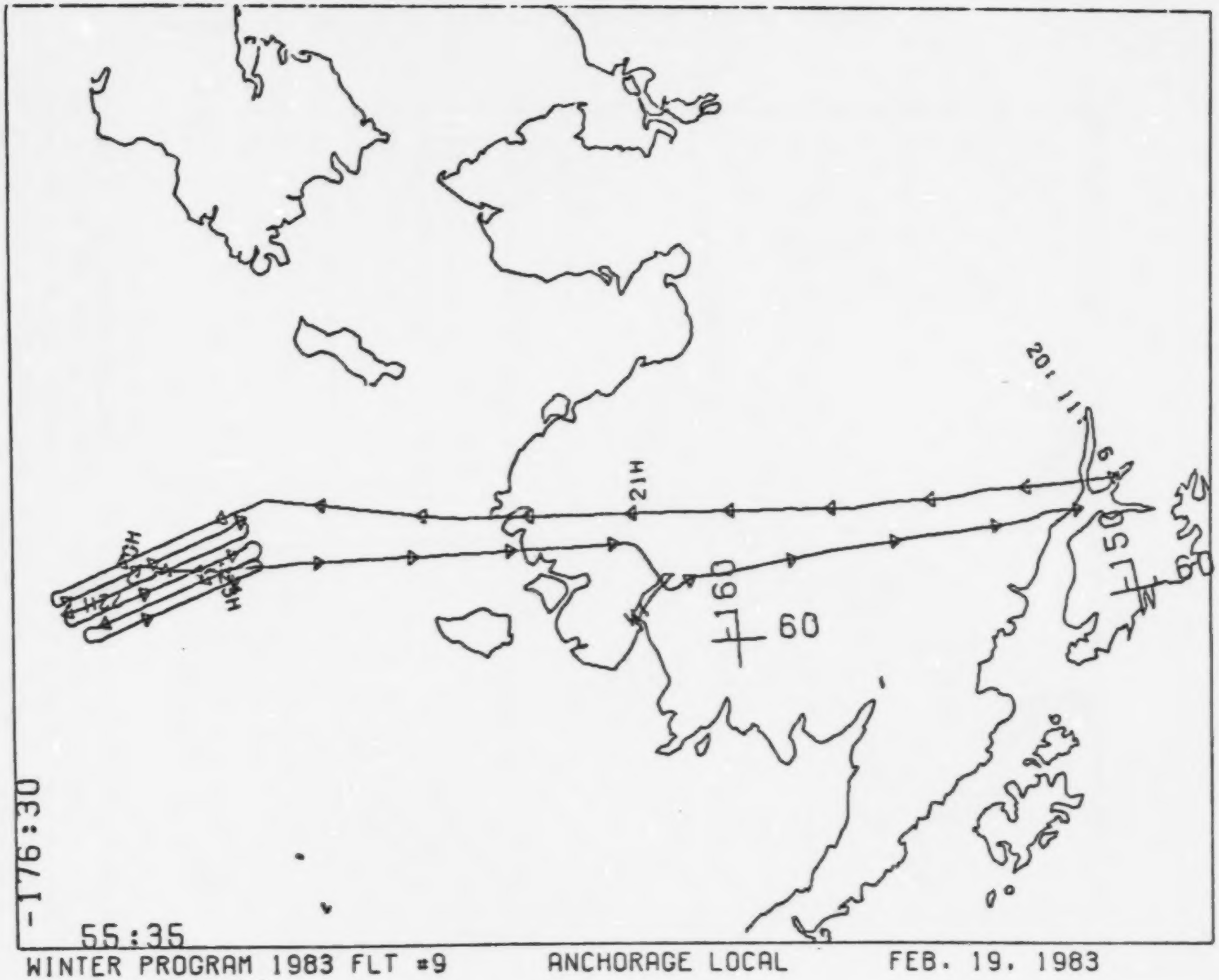

20: 11:
21H
150
60
160
60
-176:30
55:35
WINTER PROGRAM 1983 FLT #9
ANCHORAGE LOCAL
FEB. 19. 1983

FIGURE 11 FLIGHTLINE FOR NASA CV-990, 19 FEBRUARY 1983, SHOWING THE MOSAIC LINES NEAR ST. MATTHEW ISLAND

clouds, which appear at the ice edge (Figure 12). Other than noting the ice edge at 57°61'N, 169°77'W, little ice data were collected. The NASA CV-990 flew a pattern which mosaicked ice conditions around St. Matthew Island into Navarin Basin (Figure 13). The data included the thick ice in the shear zone north of the island, the polynya, and ice bands along the ice edge. The CV-990 also flew two low-level runs over the polynya to obtain high resolution radiometer data over thin ice and a return ferry parallel to the ice edge to image edge conditions.

Figure 14 shows the ice conditions near St. Matthew Island as recorded by visual ice observations from February 19 to 21, 1983. The open water portion is significantly smaller than the area usually discernable using NOAA imagery for analyzing ice types. The area generally defined as new/open water on NOAA charts appears to correspond with the combined areas of open water and water with pancake ice found in Figure 13. In the visual record, large ice floes were observed to break off the ice arch between Hall Island and St. Matthew Island and move rapidly downwind becoming incorporated into a thin ice matrix. The pancake ice itself showed evidence of wave action and downwind herding even with the limited fetch. The area described as "mottled" on the imagery refers to larger floes of new ice formed by pancake ice which congealed downwind. These floes no longer behaved as indivvidual pancakes, but often fractured through the pancakes incorporated in their surface. The edges of these new floes became raised due to floe-floe interactions, creating rounded ice forms.

By comparison, Figure 15 illustrates the polynya conditions observed from the P-3 on February 18 near St. Lawrence Island. Here the open water extent was greater, but the ice which was similar to mottled ice near the middle of the island. The ice near the western side formed large sheets of new ice which then fractured into rectangular floes, apparently due to effects of the wind waves. Since radiometers measure only approximately the first 10 cm of the ice cover (McNutt, 1982), these ice types should appear radiometrically similar.

2/21/83 Meyer-west Charlie

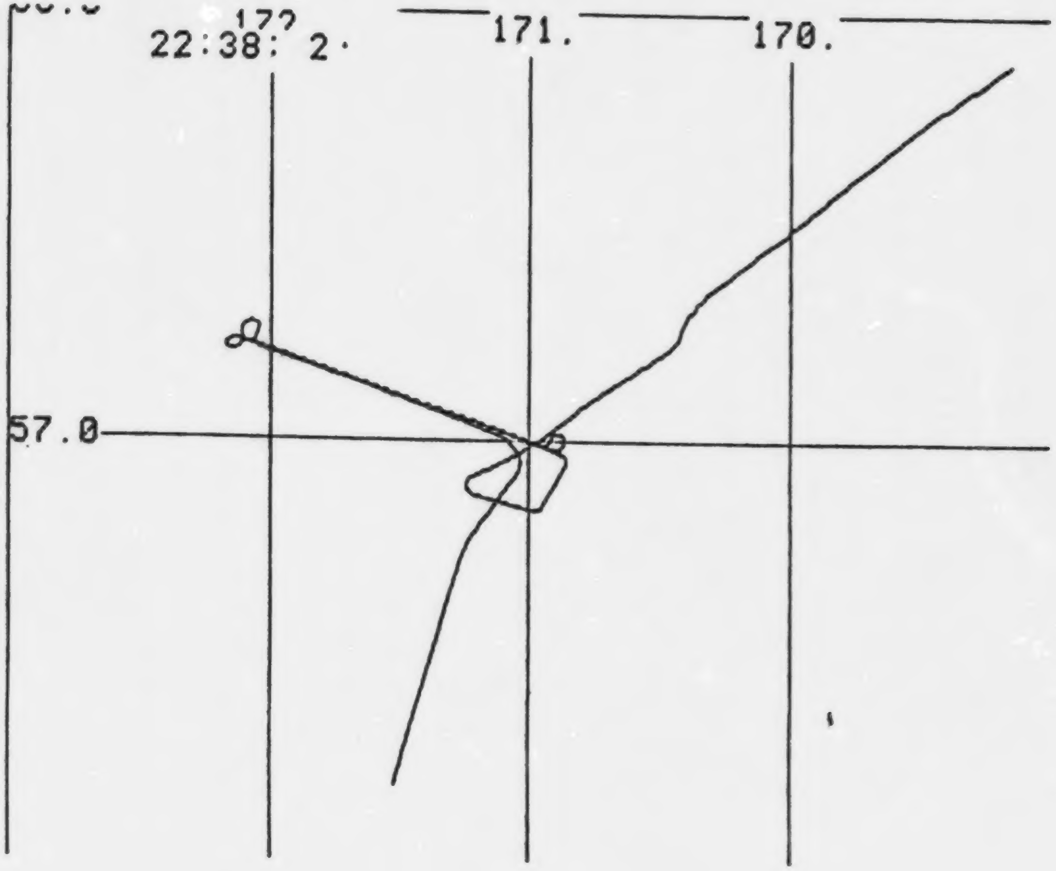

22:38: 2.
172
171.
170.
57.0

FIGURE 12 PORTION OF NOAA P-3 FLIGHTLINE FOR 21 FEBRUARY 1983

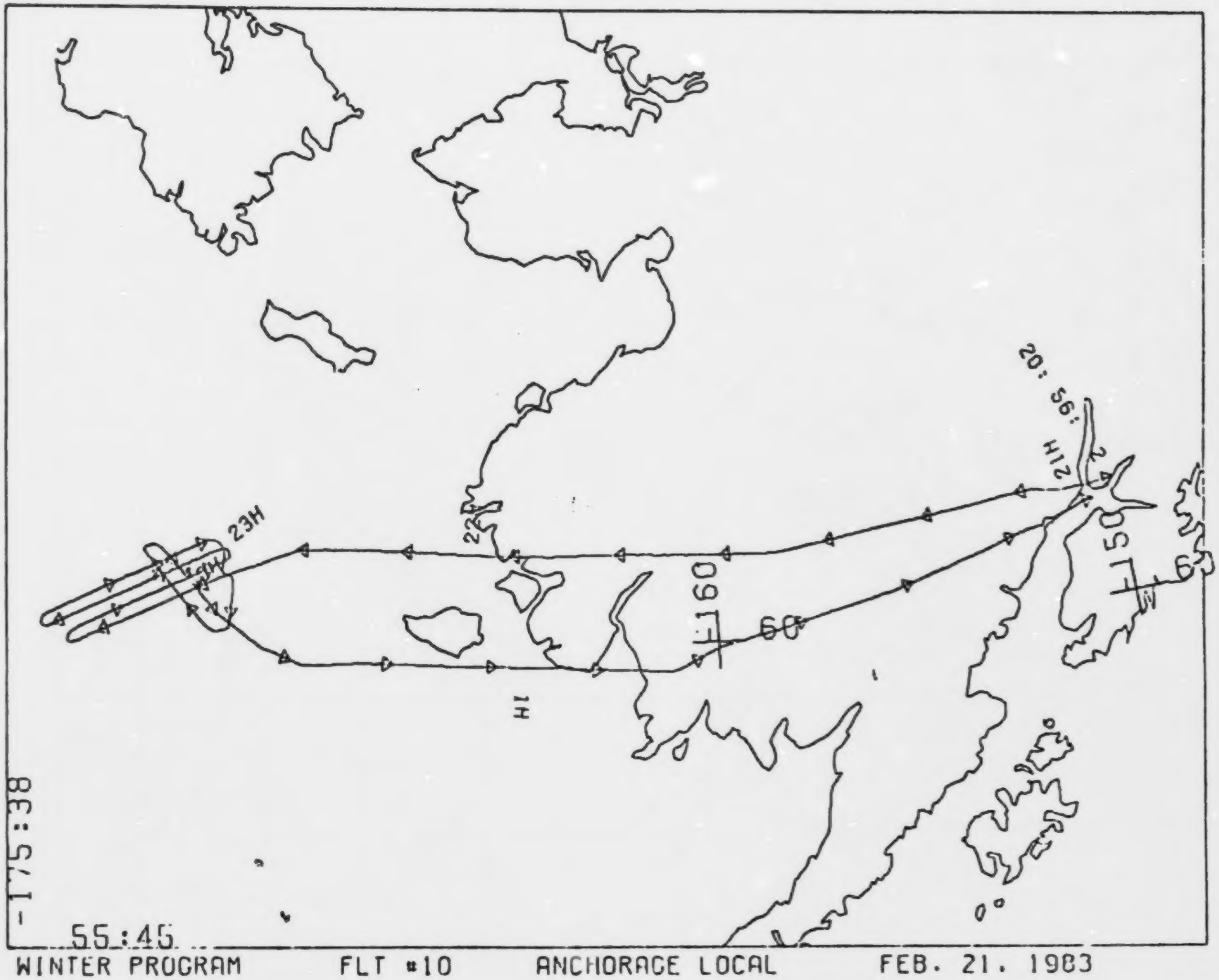

20: 56:
21H
2
150
6
160
60
22
23H
1H
-175:38
55:45
WINTER PROGRAM
FLT #10
ANCHORAGE LOCAL
FEB. 21. 1983

FIGURE 13 FLIGHTLINE FOR NASA CV-990, 21 FEBRUARY 1983, SHOWING MOSAIC LINES NEAR ST. MATTHEW ISLAND, AND LOW LEVEL RUN OVER THE POLYNYA

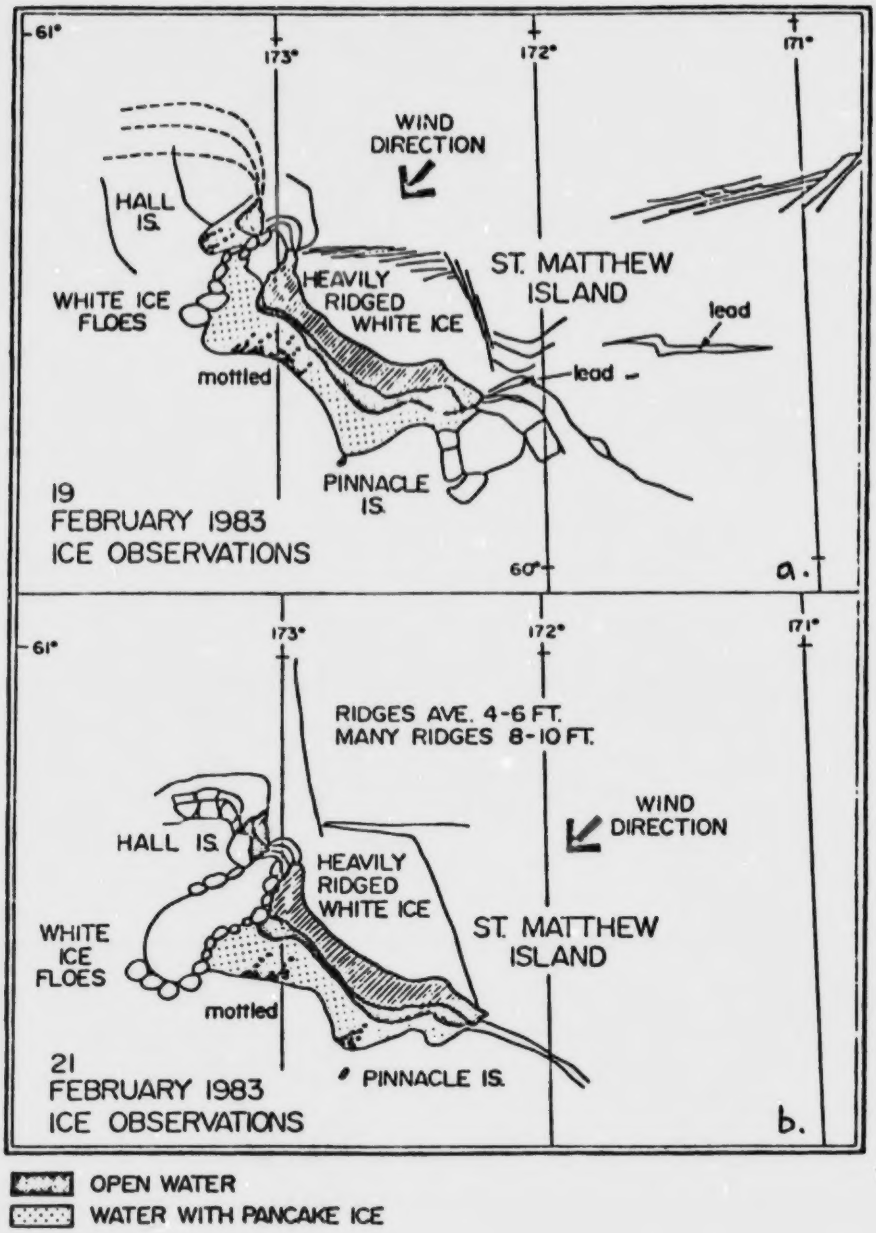

61°
173°
172°
171°
WIND DIRECTION
HALL IS.
WHITE ICE FLOES
HEAVILY RIDGED WHITE ICE
ST. MATTHEW ISLAND
lead
lead
mottled
PINNACLE IS.
19 FEBRUARY 1983 ICE OBSERVATIONS
60°
a.
61°
173°
172°
171°
RIDGES AVE. 4-6 FT.
MANY RIDGES 8-10 FT.
WIND DIRECTION
HALL IS.
HEAVILY RIDGED WHITE ICE
ST. MATTHEW ISLAND
WHITE ICE FLOES
mottled
PINNACLE IS.
21 FEBRUARY 1983 ICE OBSERVATIONS
b.
OPEN WATER
WATER WITH PANCAKE ICE

FIGURE 14 SCHEMATIC DIAGRAM OF ICE CONDITIONS OBSERVED NEAR ST. MATTHEW ISLAND: (a) 19 February 1983, (b) 21 February 1983

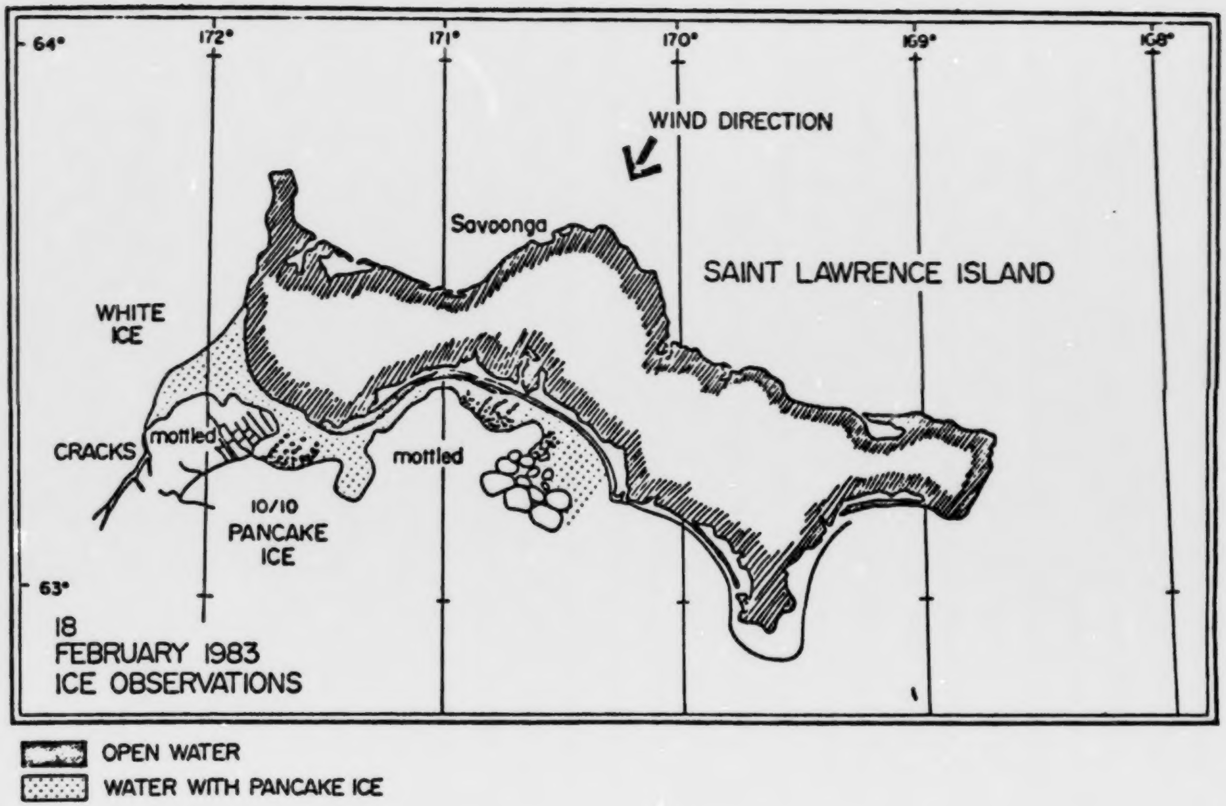

64°
172°
171°
170°
169°
168°
63°
WIND DIRECTION
Savoonga
SAINT LAWRENCE ISLAND
WHITE ICE
CRACKS
mottled
mottled
10/10 PANCAKE ICE
18 FEBRUARY 1983 ICE OBSERVATIONS
OPEN WATER
WATER WITH PANCAKE ICE

FIGURE 15 SCHEMATIC DIAGRAM OF ICE CONDITIONS OBSERVED AT ST. MATTHEW ISLAND, 18 FEBRUARY 1983

5. FURTHER DATA INVESTIGATIONS

The MIZEX West 1983 experiment successfully obtained a multi-level data set documenting ice conditions in the Marginal Ice Zone of the Bering Sea. It also successfully demonstrated the utility of the near real-time SMMR satellite ice concentration charts provided by Atmospheric Enviromental Service, Canada for use in operational planning during cloudy conditions. Studies and further analysis of the data sets require funding by the governmental agencies involved. At this point, many of the initial objectives will be met to provide a substantial body of knowledge which will help investigators analyze the air-sea-ice interactions in the area. An ice forecasting model for the Bering Sea has been developed by NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle and should be operational by 1984 (Pease and Overland, 1983). Information resulting from MIZEX West studies will enhance the accuracy of the remote sensing data expected to be used as input to this model.

Appendix A lists the types of data collected from all platforms, and the investigators responsible for each. A MIZEX West meeting will be held in January, 1984, at which time investigators will decide on the best data days available and the methodology to be used to best combine data sets. For further information on data processing and availability please contact the responsible party listed.

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REFERENCES

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APPENDIX A

MIZEX WEST EXPERIMENTAL DATA
CONTACT AND AVAILABILITY
MAY 1983

MIZEX WEST Experimental Data
Contact and Availability
May 1983

DATA	CONTACT			AVAILABLE
NOAA satellite data	Bruce Webster, National Weather Service, ANC (907) 271-3471. Jim Overland has a copy of this data available for review this week.			Immediately
Helo underflights	Andrew Cowan - see xeroxes of transparencies. Data reproductions will be available for a small user fee.			Fall 1983
Surface measurements	Tom Grenfell - radiometry information will be on graphs and tables - he will copy for those interested.			Fall 1983
Ice Floe Log DISCOVERER	Robin Muench (done on the Apple computer on board the DISCOVERER)			Immediately
Surface Microwave Observations	Rodney Knight - surface measurements			Immediately
Shipboard Meteorology	Mike Reynolds:			
	MET Camp 2			
	Wind Velocity Avg	rel to ice motion-ht =	3m.	Immediately
	Wind Direction	" " " "	3m.	"
	Current Speed	" " " "	depth = 2m.	"
	Current Direction	" " " "	" "	"
	Air Temperature			"
	Water Temperature			"
	Floe Orientation			"
	Max. Wind Gust	" " " "		"
	Mean Wind Speed	" " " "		"
	Mean Current Speed			"
	MET Camp 1 (main camp)			
	Wind Velocity Avg	rel to ice motion	3m.	Immediately
	Wind Avg. Direction	" " " "	3m.	"
	Current Velocity Avg.	" " " "	2m.	"
	Current Avg. Dir.	" " " "	2m.	"
	Air Temp.	" " " "	3m.	"
	Water Temp.	" " " "	2m.	"
	Floe Orientation	" " " "	-	"
	Max Wind Gust	" " " "	3m.	"
	Mean Wind Speed	" " " "	3m.	"
	Mean Current Speed	" " " "	2m.	"
	Atmos. Pressure	" " " "	-	"
	Water Salinity	" " " "	2m.	"
	Avg. Current Speed	" " " "	6m.	July 15
	Inst. Current Dir.	" " " "	6m.	July 15
	Loran Hourly Position	" " " "	6m.	July 15

DATA	CONTACT	AVAILABLE
Shipboard Meteorology	Mike Reynolds: (cont)	
Ice Motion	Ice Motion: all stations available by –	July 15
	(a) ARGOS fixes will be edited and resampled by spline fits for 1/2 hourly positions and velocities	
	(b) All above meteorological and oceanographic velocities will be corrected for ice motion and archival tapes will be prepared in absolute coordinates	
Shipboard Data	Mike Reynolds: DISCO met log-hourly readings WESTWIND met log-hourly readings	
	Wind speed true	Immediately in raw form
	Direction true	
	Ship Speed	"
	Position	"
	Air Temp	"
	Water Temp	"
	Humidity	"
	Upper Air Soundings	
	Pressure-height	July 15
	Temperature-potential temp.	"
	Mixing Ratio	"
	Calculated variables (equivalent potential temperature, relative humidity, etc.)	"
DISCOVERER Ice Drift and Wave Data	Peter Wadhams	
	Radar transponder drift trucks & positions (5-10 min. intervals)	Immediately on request
	"Seadisc" one-dimensional wave data from buoys deployed on ice and in water - (covering most days of experiment)	raw data-May tape(digitial) Immediately
	ENDECO directional wave buoy data (approx. 1hr per day) raw data on 3 channels or digital tape - First instance calibrations from ENDECO may be available from Seelye Martin	Immediately
	Ice core (S,T) and thickness data from drillings on 10 ft. square grid available in report from R. Muench	Immediately
	DISCOVERER positions at 10 m/h intervals	Printout - Immediately
	NB all days where there were P-3 or 990 overflights in all 5 of the categories	
NOAA P-3 Data Sets	Jim Overland - SLAR film - Data products will be available by the end of summer - D. Ross will send the original film which can be copied.	Fall 1983
	Laser data can also be sent for duplication	Immediately
	Copies of report are avialable from Jim Overland and tell where further data is and when available.	Immediately

DATA	CONTACT	AVAILABLE
Oceanography CTD Data-WESTWIND	Robin Muench	Immediately
CTD Data-DISCOVERER	Jim Schumacher Will be in the NOAA data system when complete	1 month
Current Data	Current Data Will be in the PMEL data system when complete	2 months
Alpha Helix Cruise Report		Immediately
Surface Temperatures	Will be coming out in presentations over the next	6 months
Radar Tracked Buoys	Seelye Martin Preliminary information now available	Immediately
	Data report with printout of buoy positions (punch cards or mag tape) --------------------	Immediately
	Data Report	10 days
Accelerometer Data	Seelye Martin (20 min periods every hr for 12 days at 5 Hz)	July 1
	Preliminary data report describing what is available	Mid-July
Wave Measurements ENDECO	Seelye Martin (data has been read and graphed-ENDECO data should be available by 1 Aug)	August 1
Spectra/Accelerometer Data WESTWIND	Vernon Squire	Immediately
Ablation Experiment Data	Ed Josberger	
	1) Ablation data - 7 points somic melt gauge	?
	2) current meter record: $\vec{u}$ & T	∿48 hours
	3) met - tower: $\vec{u}$ & T	∿48 hours
	4) ice temperature	∿48 hours
	Available on DEC floppies RSX-11 or RT-11 or graphical, tabular etc.	
Ice Morphology and Processes	**L. McNutt** **Maps**	**February 10,18,21**
		Mar. 84
Aircraft Radiometer **CV-990 Photography**	**Don Cavalieri**	**Mar. 84**
Aircraft Altimeter	**John Powell**	**Mar. 84**

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16. Bruce Webster
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THE NAVY/NOAA OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM - PROVIDING CONVENTIONAL AND REMOTELY-SENSED DATA IN REAL-TIME FOR SCIENTIFIC AND COMMERCIAL APPLICATIONS

by

D.R. MONTGOMERY

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

ABSTRACT

The Navy Oceanographic Data Distribution System (NODDS) is a computer-oriented system which provides access to, and distributes, operational global marine weather and oceanographic data products to private-sector users. Selected satellite data, including ice observations, are available on demand-basis in the users' facilities and can be displayed in alpha-numeric and graphics format. The NODDS is a user-supported system which operates on a fee basis. Product distribution is available in both the U.S. and Canada for marine and arctic applications. Current users include offshore oil and gas operators, private forecasting firms, ship routing operations, and commercial fishing associations.

1. INTRODUCTION

The Navy/NOAA Oceanographic Data Distribution System (NODDS) is a unique, user-oriented data system which provides meteorological and oceanographic data and products to a broad range of private sector and government users based in both the United States and Canada. The NODDS is co-located with and operationally based upon the computational facilities of the U.S. Navy-Fleet Numerical Oceanography Center (FNOC) in Monterey, California. The Navy-FNOC compiles oceanographic and meteorological data, and operates models of the ocean and atmosphere in order to provide the operational Navy with analyses and forecasts of oceanographic and atmospheric parameters at any global location.

The NODDS was formerly termed the Satellite Data Distribution System (SDDS), and was designed and implemented to support the commercial evaluation of the National Aeronautics and Space Administrations' Seasat Program - a program which led to the launch and operation of the first U.S. satellite dedicated to the observation of the global oceans. Upon the completion of the Seasat support activities, the SDDS was placed under the cognizance of both the U.S. Navy and the National Oceanic and Atmospheric Administration (NOAA). The NODDS can now routinely provide all unclassified satellite data and operational products prepared by the Navy-FNOC to U.S. and Canadian users in a variety of formats. Figure 1 depicts in pictorial form the configuration of the NODDS.

The NODDS is a user-supported system with all private-sector users obtaining data products on the basis of a modest user charge. A list of the current users of the NODDS is shown in Figure 2.

2. SYSTEM DESCRIPTION

The Naval Oceanography Command is the world's foremost oceanographic and marine weather analysis and forecasting system. It is this capability that forms the basis of the NODDS and provides its unique capability. The FNOC system, as opposed to others, is shaped by and is specialized to service the requirements of the Naval operating forces. The Naval Oceanography Command is charged with the responsibility to provide the operational Navy with analyses and forecasts of oceanographic and atmospheric parameters at any global location in the Navy's operational environment including subsurface, surface, and air. This task requires the employment of special data gathering networks, rapid communications, sophisticated numerical models, high powered computers, and highly dedicated personnel.

The highest concentration of oceanographic/meteorological data, models, computers and specialists in the Navy is at the Fleet Numerical Oceanography Center (FNOC), Monterey, California. It is here that the Navy models the ocean and the atmosphere as a coupled system, receives significant amounts of raw data, and returns operationally important environmental parameters to the Fleet Commanders through the various oceanography centers of the Naval Oceanography Command. The Fleet Commanders, in turn, establish ship/aircraft tactics, sensor selections, and weapon settings, based in part on the environmental situation predicted by FNOC.

Figure 3 depicts the system by which the various mainframe computers and the peripheral computers are linked to each other; specifically to be noted is the manner with which the Satellite Processing computer (CYBER-175) ties into the Primary Environmental Prediction System (CDC 6500s and CDC CYBER 720) or can be operated as a completely independent satellite data processing system. Noted in this diagram are the two data communications networks, the Consolidated Communications System and the NODDS. Figure 3 also identifies the mainframe computers utilized by FNOC for the processing of environmental data and the operational runs of the numerical models. These mainframe computers are:

(a) Satellite Processing Center (SPC). The Fleet Numerical Satellite Processing Center computer is a CDC CYBER-175. This computer is designed to function as a multi-processing, multi-programming system whose central memory has been augmented with an extended core storage (ECS). As configured, the CYBER-175 has 14 peipheral processors, 24 IO channels and 2 extended core storage banks of 500K decimal words (60 bits) each.

(b) Hydroclimatology Computer (HCC). The HCC computer is a CDC 6500. This computer serves as a research and development computer, provides access to historical data and fields, and can be used to augment the primary environmental prediction system computers if an overload in the normal operating run occurs.

(c) Primary Environmental Prediction System (PEPS). The PEPS system is composed of two CDC 6500 computers. On these computers, which are linked by an extended core storage, are run the oceanographic and atmospheric analysis/prediction models. The output from these models feeds a variety of specific tactical models for application in naval operations.

(d) Primary Environmental Prediction System Upgrade (PEPSU). The PEPSU computer is a CDC CYBER-203 front-ended by a CDC CYBER-170/720. Due to the Naval Oceanography Command's responsibility to provide the naval forces with global oceanographic and atmospheric products, complex, sophisticated models have had to be developed which require a speed of computation in excess of those computers previously installed at Fleet Numerical. Installation of the PEPSU system is scheduled for completion in late 1980.

Figures 4 and 5 illustrate the means by which satellite data is processed by the SPC. At the present time, raw satellite data can be received by the High Speed Communications System (HSCS) through two antennae installed at Fleet Numerical (RCA for NIMBUS) (AMSAT for DMSP).

The HSCS processes, in real time, an input of two serial data streams. It is used to receive, store, and format data from environmental satellites for input to the Satellite Processing computer. The input serial data rate is 1.344 megabits/second per data line. HSCS has the capability to process in real time at a data rate of 2.688 megabits/second.

Data is processed by the HSCS onto the Extra High Capacity On-line (EHCO) disc storage. EHCO is comprised of eight CDC 844-41 discs. This is a temporary storage area for the HSCS formatted data prior to geophysical processing by the CYBER-175. Additionally, a minor segment of EHCO is used for storage of operating messages that are passed back and forth between HSCS and the CYBER-175. EHCO has the capacity for storing 11.376×10^9 bits of data.

When the satellite data has been processed, it is transferred from the CYBER-175 to the High Capacity Random Access storage (HCRA) (16 CDC 844-41 discs). These discs are the shared storage between the CYBER-175 and the PEPS mainframes. The HCRA is also used to place large data bases on-line for use by both the CYBER-175 and the PEPS mainframes. Storage capacity of the HCRA is 22.752×10^9 bits of data.

From the HCRA the data may be distributed as processed satellite data over the Satellite Data Distribution System, or it may be utilized as input data to initialize oceanographic/atmospheric models on the PEPS mainframe computers.

Shown in Figure 6 are the satellites which provide data to FNOC. FNOC does not process data from all of the satellite sensors. The sensors utilized are those whose data enhance or give a new dimension to the analysis and forecast capability at Fleet Numerical in support of naval operations. Figure 8 indicates the satellite and sensor, parameter measured, and the Fleet Numerical model usage.

FNOC does not process raw TIROS-N data. The data is received via a land communication circuit in a processed format from the National Environmental Satellite (NESS) in Washington. Upon receipt, the data is readily ingested into the geophysical data base. Fleet Numerical has the capability to process raw data from DMSP, NIMBUS, and GOES.

The Data Distribution System itself is a PDP 11/60 computer which receives the environmental data files, processed and formatted to meet predetermined user needs, stores them and transmits them to the commercial users upon user request. The hardware configuration includes the PDP 11/60, a high-speed data link interface (DRHCD) connecting the 11/60 and the FNOC CDC-6500 computer (HAL), disk drives, a tape unit, a DH-11 AD interface unit controlling up to 16 asynchronous ports, and two DU-11 interface units supporting synchronous computer-to-computer communications. The operating system for the 11/60 is the RSX 11M Version 3.

Network Communications Subsystem - This subsystem consists of the Telenet TP 2200 Telecommunications Processor, the Tymenet (U.S.) and Datapak (Canadian) networks, the telecommunications link for non-Telenet users, and all necessary modems. This subsystem provides the link between the host computer equipment located at FNOC in Monterey and the user terminals located at geographically dispersed locations in the United States and Canada. The asynchronous data links are 1200 baud links and the synchronous links are 4800 baud links.

User Terminal Sets - This subsystem consists of all the terminals, computers, and hard copy devices which will receive the user weather and ocean data from the PDP 11/60. The terminals include Tektronix CRT displays with hard copy units attached. The computers used represent various scientific computers emulating CDCs 200 UT protocol.

A hierarchy of jobs and catalogued procedures exist which are called when appropriate elemental meteorological and oceanographic data fields are produced in PEPS and SPC. They cause these fields to be routed to HAL. Once in HAL the fields are formatted and create files which contain the meteorological and oceanographic data products the users have requested. The user files are then routed to the PDP 11/60. A file transfer process (FTP) is used to transfer the user specific files from HAL to the PDP 11/60. The transfer process is accomplished without manual intervention. A job is run on the HAL computer which causes the FTP to transfer the files from the appropriate output queue of HAL to the Product Input Queue in the PDP 11/60.

AM applications software module resides in the PDP 11/60. This module takes the weather and ocean products in the Product Input Queue, determines the users whose directories contain pointers to these new products, and updates the user product directories accordingly. This module is scheduled to be run every 15 minutes so that the user product directories will be maintained in a near real-time state.

Additional applications software modules reside on the PDP 11/60 to allow the user to obtain his desired products. These modules allow the user to inspect the contents of his product directory (DIR), and to select the products required. There are several modules which can be accessed by privileged users to create, monitor, and update the user directories and files on the PDP 11/60. Updating user requests and changes is generally performed only once per month.

Figure 7 depicts the method in which raw satellite data is received by FNOC, converted to geophysical data records (meaningful parameters ^{o}C, meters, etc.) for the various parameters (sea surface temperature, wind fields, wave heights, etc.), combined with data from other sources, and finally ingested into the basic physical model as the initialized condition. The physical model then time steps forward, producing a forecast of expected conditions.

As seen in previous figures, the NODDS receives environmental data and products from the FNOC computers. The NODDS converts these data into data products in formats which are compatible with commercial user requests, and delivers these products, upon demand, to the users' terminals, hard copy devices, or computers. The system is interactive in that the user accesses the system, learns from the system what products are available for delivery, selects these products to be delivered, and then the system sends the requested information. The

NODDS consists of several hardware components and software modules. The hardware and software can be broken down into three subsystems:

(a) The Data Distribution Subsystem - a PDP 11/60 with the necessary peripheral devices and applications software which run on FNOC computers and on the 11/60.

(b) The Network Communications Subsystem - teleprocessing equipment and network links which deliver data from the UDDS to the user locations.

(c) The User Terminal Set - the set of receiving equipment located at the users' facilities which receives the data sent over the network.

3. NODDS PRODUCTS

As shown in Figure 3, the FNOC environmental products which are available to the NODDS are derived from the operational mainframe computers. A list of the data and products which are currently on the NODDS is shown in Figures 8, 9, 10 and 11. Most NODDS users utilize products in a graphics format which are received and copied principally on Tektronix series 400 terminals and hardcopy units. Graphic data and products are available at a 1200 baud data rate. Some products are available in both graphics and tabular formats. Others are available only in a tabular form. These tabular data are available at both 300 and 1200 baud rates. This lower rate permits users to utilize teletype terminals for the receipt of data. Large volume users accept data and products in a binary format which permits data, in a field format, to be transferred from the NODDS computer to the users' computers at a 4800 baud data rate.

Examples of these NODDS products are shown in Figures 12, 13, 14 and 15. Figure 12 depicts isotherms of sea surface temperature (SST) analysis for a region in the Gulf of Alaska and the Bering Sea. Figure 13 is a graphic product showing lines of constant mixed layer depth for the same regions. A surface pressure twelve (12) hour forecast is shown in Figure 14. Figure 15 illustrates a satellite-derived product. In this example, the Earth-located brightness temperatures from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) are listed. This tabular listing of data is processed by some users through appropriate algorithms to obtain estimates of ice concentrations, ice edge location, and the distribution of first-year and multiyear ice. Ph.D. Associates of Toronto, Canada, has done significant work to develop limited operational ice products on a near-real time basis utilizing satellite data from the NODDS.

4. USER CHARGES

The NODDS operates on a user-charge basis which provides some cost recovery for system operations. A summary of this user charge policy is shown in Figure 16.

5. ACKNOWLEDGEMENTS

The author wishes to thank the personnel at the Navy-Fleet Numerical Oceanography Center for their support and dedication which has led to the implementation and operation of the NODDS. Special thanks are given to Captain Ronald Hughes, Captain Harry Nicholson, and Captain David Honhart for their efforts in this endeavor which has led to a unique system by which the private-sector can access important marine and oceanographic data.

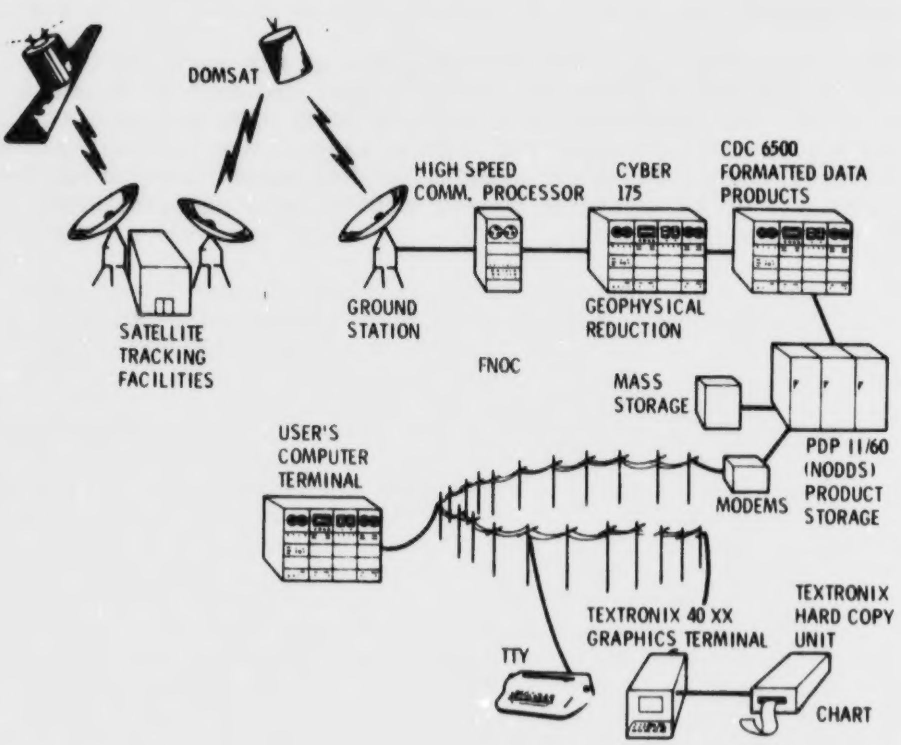

DOMSAT
HIGH SPEED COMM. PROCESSOR
CYBER 175
CDC 6500 FORMATTED DATA PRODUCTS
SATELLITE TRACKING FACILITIES
GROUND STATION
GEOPHYSICAL REDUCTION
FNOC
MASS STORAGE
USER'S COMPUTER TERMINAL
PDP 11/60 (NODDS) PRODUCT STORAGE
MODEMS
TEXTRONIX 40 XX GRAPHICS TERMINAL
TEXTRONIX HARD COPY UNIT
TTY
CHART

Figure 1. System Configuration

COMMERCIAL

- OCEANROUTES, INC.
- GLOBAL WEATHER DYNAMICS, INC.
- NORDCO
- OCEANWEATHER, INC.
- PhD ASSOCIATES
- WESTERN FISHBOAT OWNERS ASSOC.

GOVERNMENT - NON MILITARY

- U.S. COAST GUARD - AMVER
- NOAA-NMC, OCEAN SERVICES GROUP
- NOAA - COASTAL WAVES GROUP
- NOAA - NWS; ANCHORAGE, AK.
- NOAA - NWS; REDWOOD CITY, CA.

MILITARY

- NAF - MOFFETT FIELD
- NAF - NORTH ISLAND
- MILITARY SEALIFT COMMAND
- NAVY OCEANOGRAPHIC SYSTEMS - PACIFIC
- NAVAL UNDERSEA WARFARE ENGINEERING CENTER

Figure 2. Current System Users

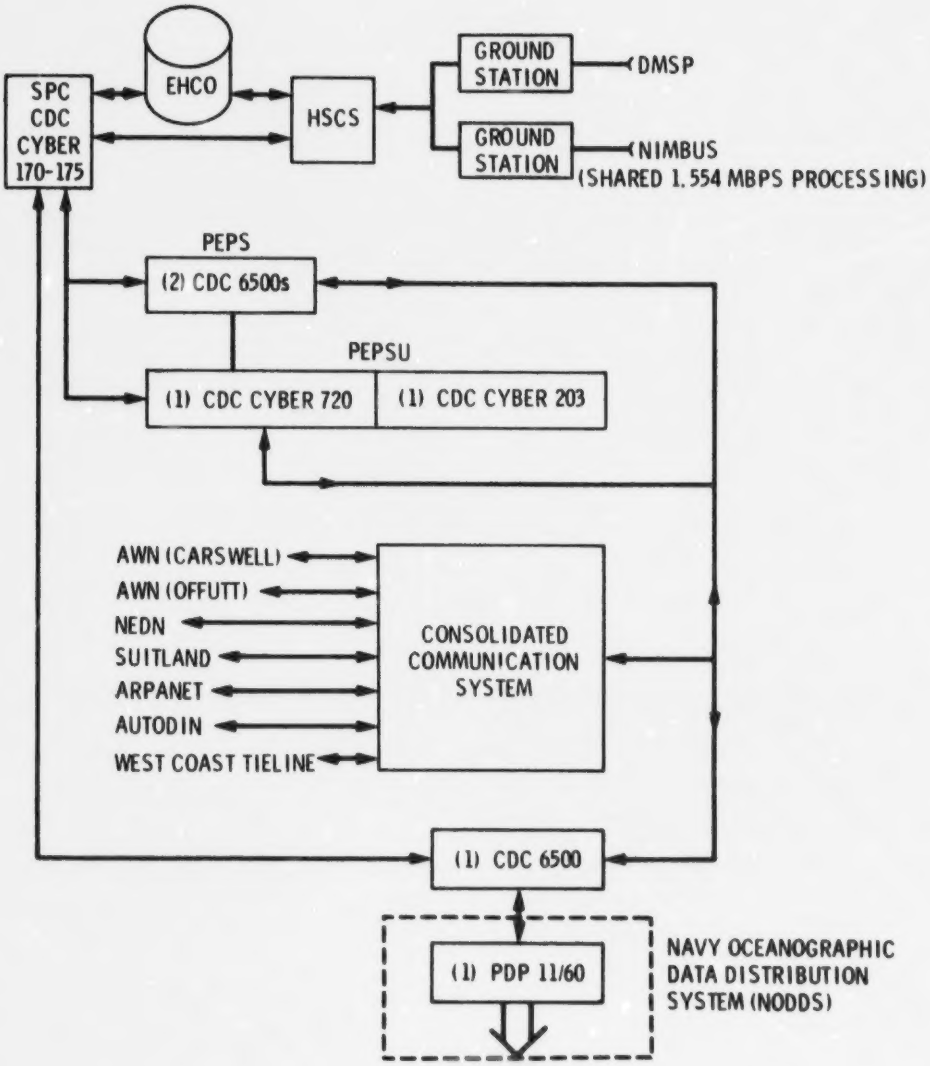
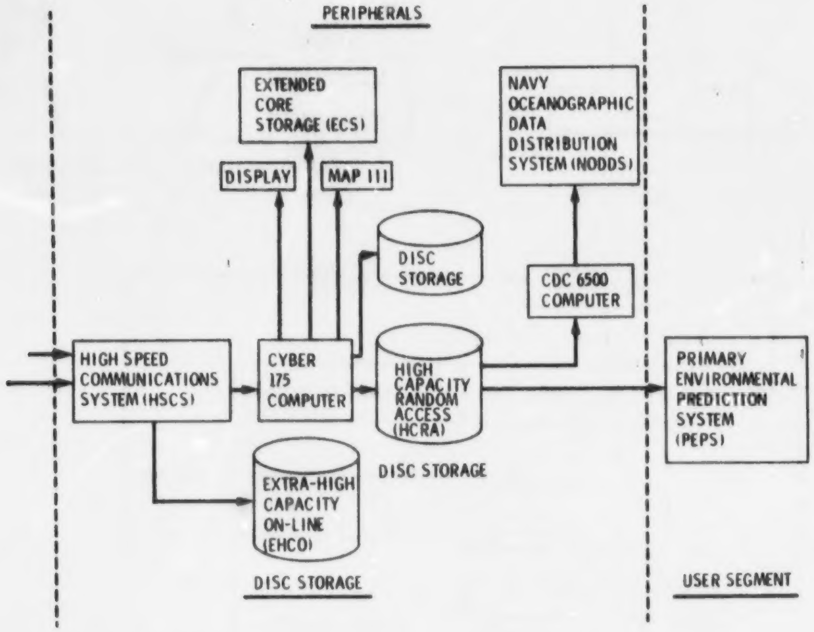
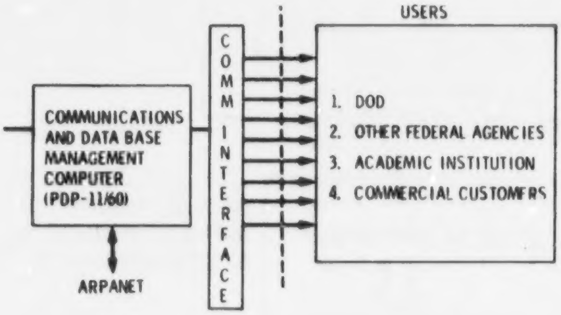

SPC
CDC
CYBER
170-175
EHCO
HSCS
GROUND STATION
DMSP
GROUND STATION
NIMBUS
(SHARED 1.554 MBPS PROCESSING)
PEPS
(2) CDC 6500s
PEPSU
(1) CDC CYBER 720
(1) CDC CYBER 203
AWN (CARSWELL)
AWN (OFFUTT)
NEDN
SUITLAND
ARPANET
AUTODIN
WEST COAST TIELINE
CONSOLIDATED COMMUNICATION SYSTEM
(1) CDC 6500
(1) PDP 11/60
NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM (NODDS)

Figure 3. Fleet Numerical Oceanography Center Computer Communications


PERIPHERALS
EXTENDED CORE STORAGE (ECS)
DISPLAY
MAP III
NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM (NODDS)
DISC STORAGE
CDC 6500 COMPUTER
HIGH SPEED COMMUNICATIONS SYSTEM (HSCS)
CYBER 175 COMPUTER
HIGH CAPACITY RANDOM ACCESS (HCRA)
DISC STORAGE
PRIMARY ENVIRONMENTAL PREDICTION SYSTEM (PEPS)
EXTRA-HIGH CAPACITY ON-LINE (EHCO)
DISC STORAGE
USER SEGMENT

NAVY OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM


USERS
COMMUNICATIONS AND DATA BASE MANAGEMENT COMPUTER (PDP-11/60)
ARPANET
COMM INTERFACE
1. DOD
2. OTHER FEDERAL AGENCIES
3. ACADEMIC INSTITUTION
4. COMMERCIAL CUSTOMERS

NOTE:

USERS MAY SELECT A VARIETY OF METHODS FOR DATA RECEPTION INCLUDING: TTY
TEKTRONIX GRAPHICS
ETC.

Figure 4. Satellite Processing Center Elements

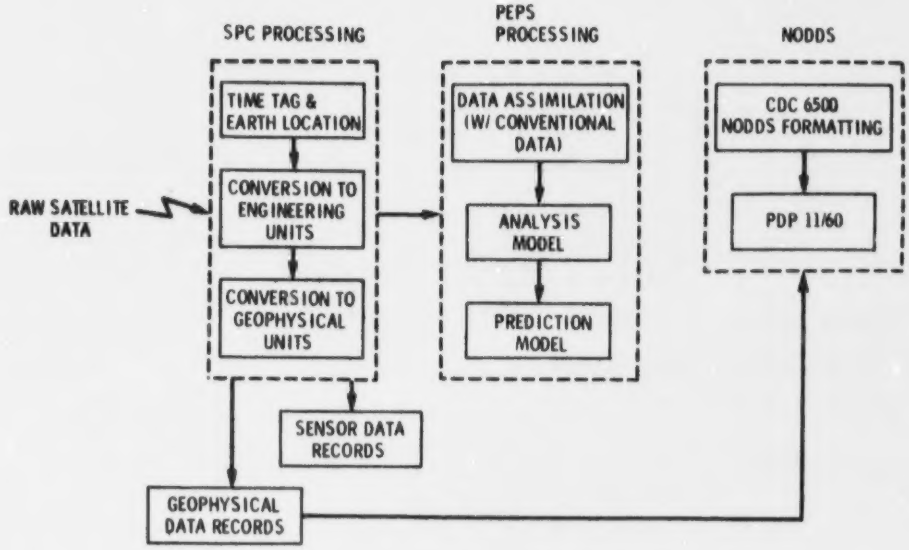

SPC PROCESSING
PEPS PROCESSING
NODDS
TIME TAG & EARTH LOCATION
CONVERSION TO ENGINEERING UNITS
CONVERSION TO GEOPHYSICAL UNITS
RAW SATELLITE DATA
DATA ASSIMILATION (W/ CONVENTIONAL DATA)
ANALYSIS MODEL
PREDICTION MODEL
CDC 6500 NODDS FORMATTING
PDP 11/60
SENSOR DATA RECORDS
GEOPHYSICAL DATA RECORDS

Figure 5. FNOC Satellite Data Processing

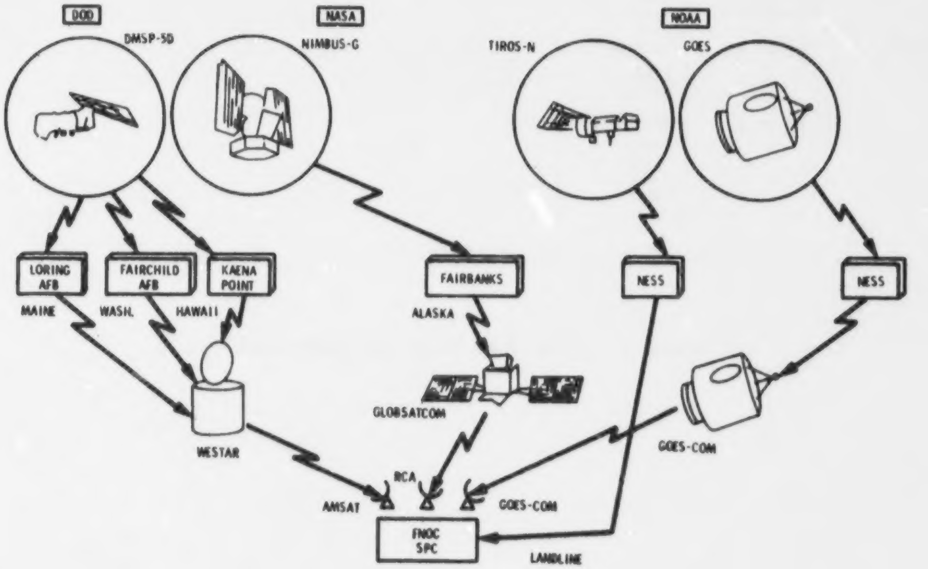

DOD
DMSP-5D
NASA
NIMBUS-G
NOAA
TIROS-N
GOES
LORING AFB
FAIRCHILD AFB
KAENA POINT
FAIRBANKS
NESS
NESS
MAINE
WASH.
HAWAII
ALASKA
GLOBSATCOM
WESTAR
GOES-COM
RCA
AMSAT
GOES-COM
FNOC SPC
LANDLINE

Figure 6. Satellite Systems and Communications Links with FNOC

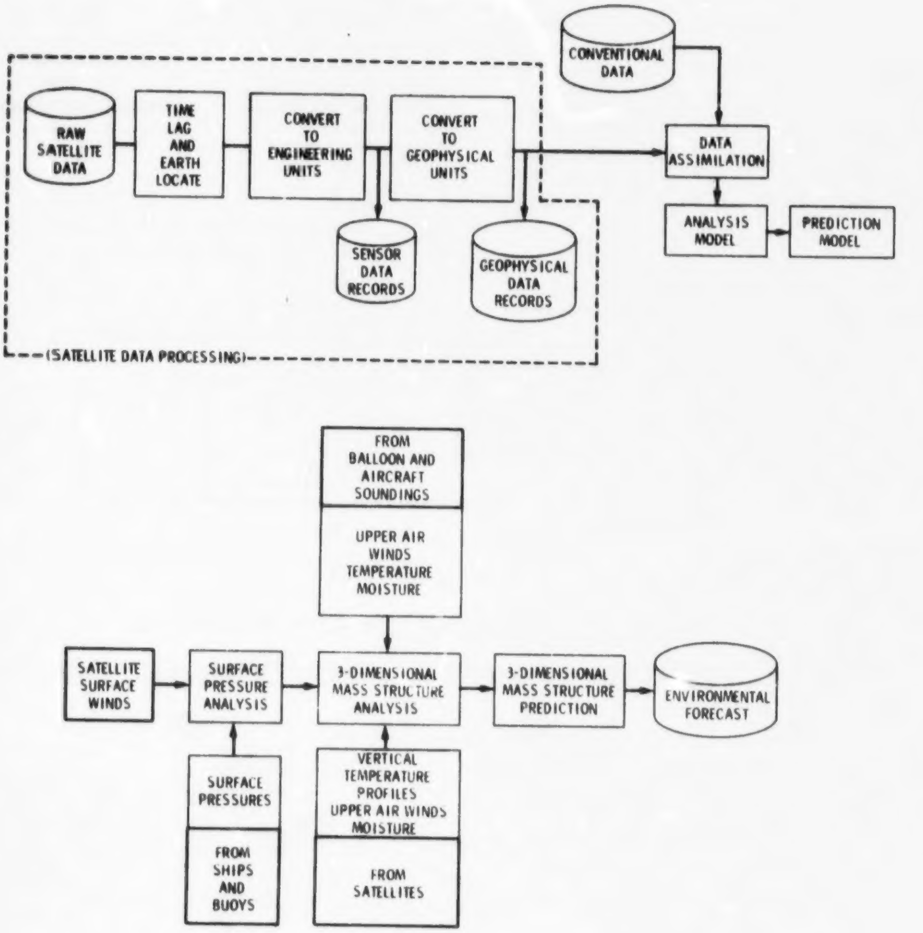

CONVENTIONAL DATA
RAW SATELLITE DATA
TIME LAG AND EARTH LOCATE
CONVERT TO ENGINEERING UNITS
CONVERT TO GEOPHYSICAL UNITS
DATA ASSIMILATION
SENSOR DATA RECORDS
GEOPHYSICAL DATA RECORDS
ANALYSIS MODEL
PREDICTION MODEL
(SATELLITE DATA PROCESSING)
FROM BALLOON AND AIRCRAFT SOUNDINGS
UPPER AIR WINDS TEMPERATURE MOISTURE
SATELLITE SURFACE WINDS
SURFACE PRESSURE ANALYSIS
3-DIMENSIONAL MASS STRUCTURE ANALYSIS
3-DIMENSIONAL MASS STRUCTURE PREDICTION
ENVIRONMENTAL FORECAST
SURFACE PRESSURES
FROM SHIPS AND BUOYS
VERTICAL TEMPERATURE PROFILES UPPER AIR WINDS MOISTURE
FROM SATELLITES

Figure 7. The Raw Data to Forecast Cycle

- GRAPHICS

NAME	AREA	TAU
SURFACE PRESSURE	NORTH ATLANTIC, GULF OF ALASKA	0, 24
	PACIFIC BASIN	0, 12, 24, 36, 60, 72
	SO. HEMISPHERE	0, 36, 96, 120
	NO. HEMISPHERE	24, 48, 72, 96, 120
SURFACE WINDS (BARBS)	NORTH ATLANTIC, GULF OF ALASKA	0, 24, 36
	PACIFIC BASIN	12, 24
SEA SURFACE TEMP	PACIFIC BASIN, ATLANTIC, GULF OF ALASKA	0
	SO. HEMISPHERE, NO. HEMISPHERE	0
SIGNIFICANT WAVE HEIGHT ($H_{1/3}$) (& DIRECTION)	NORTH ATLANTIC, GULF OF ALASKA	0, 24, 36
	PACIFIC BASIN	0, 12, 24, 36

Figure 8. Data/Products Currently on NODDS

•GRAPHICS

NAME	AREA	TAU
HEIGHT/WINDS (200 MB, 300, 400, 500, 600, 700, 850)	PACIFIC BASIN	24, 36
PRIMARY LAYER DEPTH	PACIFIC BASIN, GULF OF ALASKA	0
FREEZING LEVEL	PACIFIC BASIN	0, 24, 36
500 MB HT/WINDS	NO. HEMISPHERE	24, 48, 72, 96

•TABULAR DATA

SURFACE PRESSURE	LABRADOR SEA NEWFOUNDLAND	0, 12, 24
SURFACE WINDS	LABRADOR SEA NEWFOUNDLAND	
SIG. WAVE HEIGHT	LABRADOR SEA NEWFOUNDLAND	
SEA SURFACE TEMP		0

Figure 9. Data/Products Currently on NODDS (Continued)

•SOWM SPECTRAL POINTS

AREA	TAU
NEWFOUNDLAND, LABRADOR SEA AREA	0, 24, 48, 72
NORTH SEA (10E - 10W, 55-65N)	0, 12, 24, 48, 72
ATLANTIC PB (30-45N, 15-25W)	
GULF OF MEXICO, ATLANTIC COAST (20-45N, 60W-90W)	0, 12, 24, 36, 48
GULF OF ALASKA	0, 12, 24, 48, 72
BERING SEA/ST. LAWRENCE	0, 12
PACIFIC COAST (30-50N, 115-135W)	0, 12, 24, 36, 48

Figure 10. Data/Products Currently on NODDS (Continued)

- BINARY PRODUCTS

NAME	AREA	TAU
SURFACE PRESSURE	NO. HEMISPHERE	0, 12, 24, 36, 48, 60, 72, 84, 96, 108, 120
U COMPONENT - MARINE WINDS	NO. HEMISPHERE	0, 12, 24, 36, 48
V COMPONENT - MARINE WINDS	NO. HEMISPHERE	0, 12, 24, 36, 48
SURFACE PRESSURE	GLOBAL	0, 12, 24, 36, 48
SIGNIFICANT WAVE HEIGHT	NO. HEMISPHERE	
WAVES-PRIMARY PERIOD	NO. HEMISPHERE	0, 12, 24, 36, 48
WAVES-PRIMARY DIRECTION	NO. HEMISPHERE	0, 12, 24, 36, 48
WAVES-SECONDARY PERIOD	NO. HEMISPHERE	0, 12, 24, 36, 48
WAVES-SECONDARY DIRECTION	NO. HEMISPHERE	0, 12, 24, 36, 48
SEA SURFACE PRESSURE	NO. HEMISPHERE	0
1000 MB SMALL SCALE DISTURBANCE	NO. HEMISPHERE	0, 36
1000 MB LARGE SCALE DISTURBANCE	NO. HEMISPHERE	0, 48
500 MB SMALL SCALE DISTURBANCE	NO. HEMISPHERE	0. 48
500 MB LARGE SCALE DISTURBANCE	NO. HEMISPHERE	
TROPOPAUSE	NO. HEMISPHERE	0, 24
MAX. WIND	NO. HEMISPHERE	0, 36

Figure 11. Data/Products Currently on NODDS (Continued)

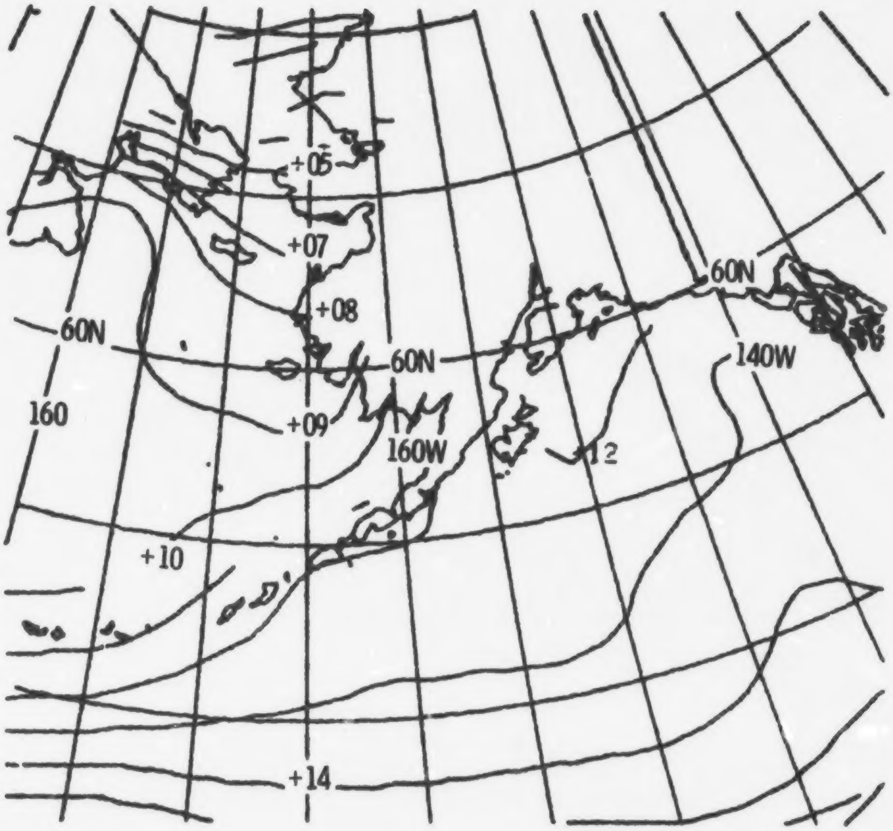

+05
+07
+08
+09
+10
+14
12
60N
60N
60N
60N
160
160W
140W

Figure 12. Isotherms of Sea Surface Temperature (SST) Analysis for a Region in the Gulf of Alaska and the Bering Sea

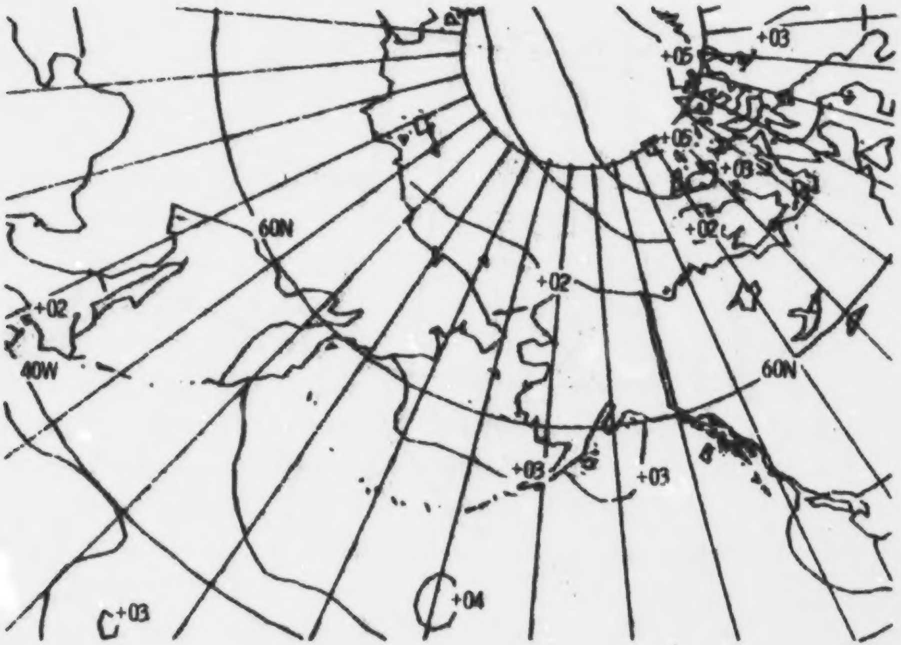

+03
+05
+05
+03
+02
60N
+02
+02
40W
60N
+03
+03
+03
+04

Figure 13. Graphic Product Showing Lines of Constant Mixed Layer Depth for a Region in the Gulf of Alaska and the Bering Sea

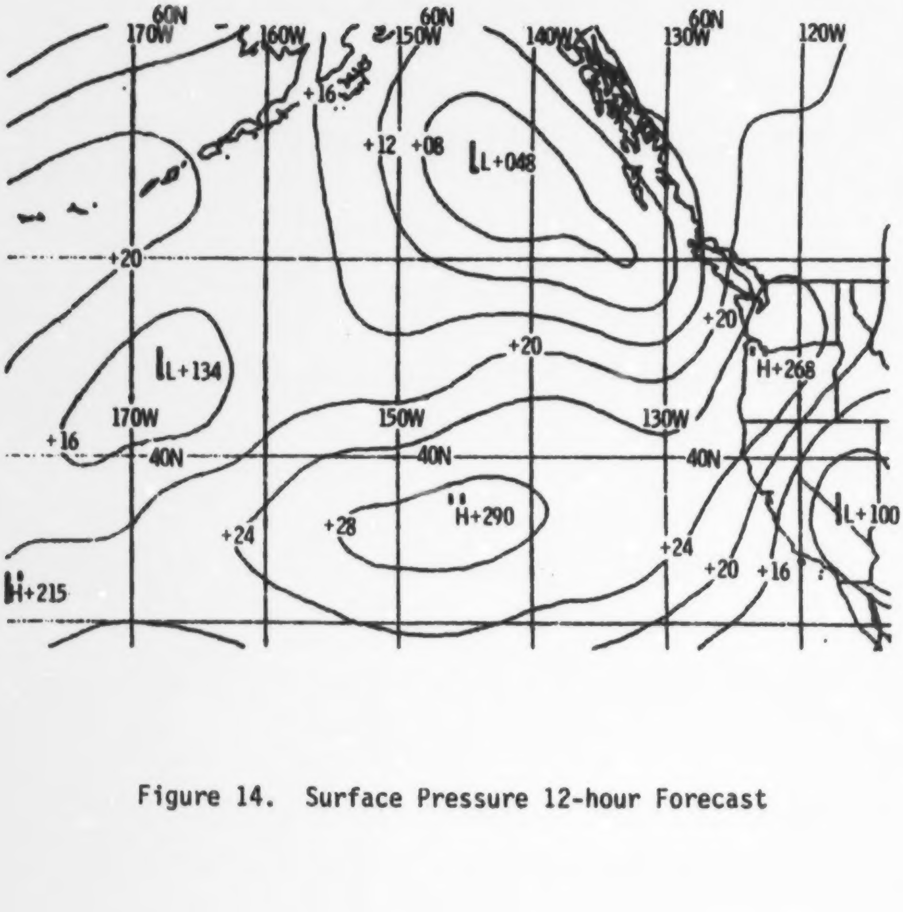
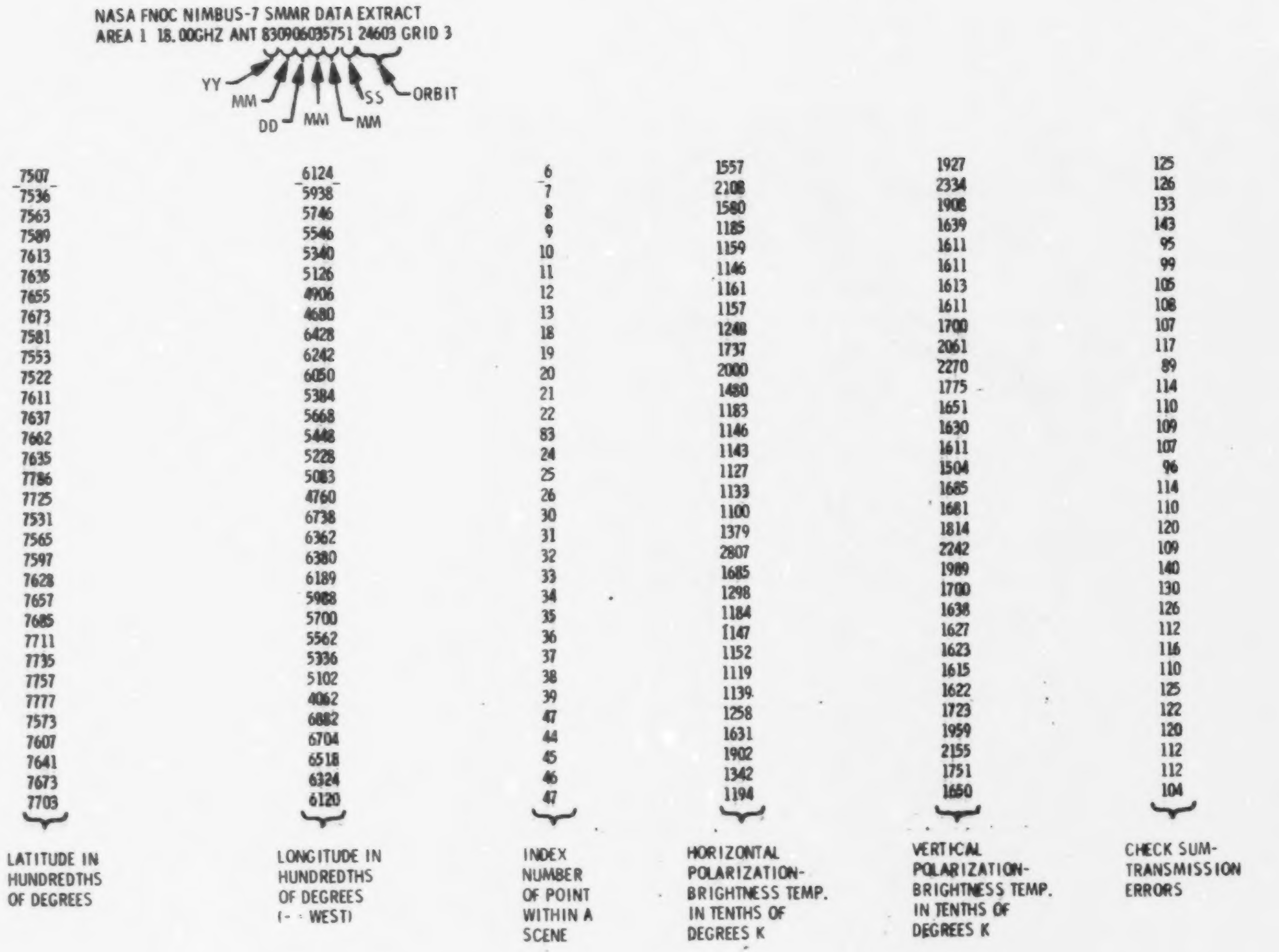

60N
170W
160W
60N
150W
140W
60N
130W
120W
+16
+12
+08
L+048
+20
+20
L+134
+20
170W
150W
130W
+16
40N
40N
40N
H+268
H+290
L+100
+24
+28
+24
+20
+16
H+215

Figure 14. Surface Pressure 12-hour Forecast



NASA FNOC NIMBUS-7 SMMR DATA EXTRACT
AREA 1 18.00GHZ ANT 830906035751 24603 GRID 3

YY
MM
DD
MM
MM
SS
ORBIT

LATITUDE IN HUNDREDTHS OF DEGREES	LONGITUDE IN HUNDREDTHS OF DEGREES (- = WEST)	INDEX NUMBER OF POINT WITHIN A SCENE	HORIZONTAL POLARIZATION-BRIGHTNESS TEMP. IN TENTHS OF DEGREES K	VERTICAL POLARIZATION-BRIGHTNESS TEMP. IN TENTHS OF DEGREES K	CHECK SUM-TRANSMISSION ERRORS
7507	6124	6	1557	1927	125
7536	5938	7	2108	2334	126
7563	5746	8	1580	1908	133
7589	5546	9	1185	1639	143
7613	5340	10	1159	1611	95
7635	5126	11	1146	1611	99
7655	4906	12	1161	1613	105
7673	4680	13	1157	1611	108
7581	6428	18	1248	1700	107
7553	6242	19	1737	2061	117
7522	6050	20	2000	2270	89
7611	5384	21	1480	1775	114
7637	5668	22	1183	1651	110
7662	5448	83	1146	1630	109
7635	5228	24	1143	1611	107
7786	5083	25	1127	1504	96
7725	4760	26	1133	1685	114
7531	6738	30	1100	1681	110
7565	6362	31	1379	1814	120
7597	6380	32	2807	2242	109
7628	6189	33	1685	1989	140
7657	5988	34	1298	1700	130
7685	5700	35	1184	1638	126
7711	5562	36	1147	1627	112
7735	5336	37	1152	1623	116
7757	5102	38	1119	1615	110
7777	4062	39	1139	1622	125
7573	6882	47	1258	1723	122
7607	6704	44	1631	1959	120
7641	6518	45	1902	2155	112
7673	6324	46	1342	1751	112
7703	6120	47	1194	1650	104

Figure 15. Illustration of a Satellite-derived Product

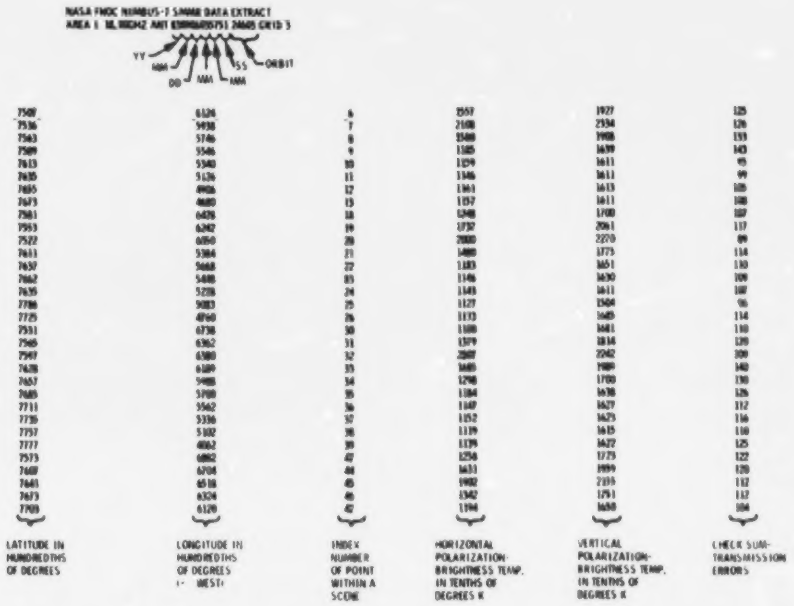

NASA FNOC NIMBUS-7 SMMR DATA EXTRACT
YY
MM
DD
MM
MM
SS
ORBIT
LATITUDE IN HUNDREDTHS OF DEGREES
LONGITUDE IN HUNDREDTHS OF DEGREES (- WEST)
INDEX NUMBER OF POINT WITHIN A SCENE
HORIZONTAL POLARIZATION-BRIGHTNESS TEMP. IN TENTHS OF DEGREES K
VERTICAL POLARIZATION-BRIGHTNESS TEMP. IN TENTHS OF DEGREES K
CHECK SUM-TRANSMISSION ERRORS

Figure 15. Illustration of a Satellite-derived Product

- USER CHARGES FOR NODDS DATA

  $10.65 PER CONNECT HOUR
  PAYABLE QUARTERLY, IN ADVANCE

- COMMUNICATIONS CHARGES VARY WITH USER LOCATION

  U.S. - TYMNET SERVICE

  CANADA - TYMNET AND DATAPAC SERVICES

- REPRESENTATIVE USER CHARGES

U.S. USERS:	$25.00 - $5000.00 PER QUARTER
CANADIAN USERS:	$16.00 - $8000.00 PER QUARTER

Figure 16. User Charge Arrangements

ARCTIC DATA COMPILATION AND APPRAISAL PROGRAM:
OCEANOGRAPHY AND THE CANADIAN BEAUFORT SEA

by

B.D. SMILEY, A.B. CORNFORD and G.S. FLOYD

Institute of Ocean Sciences
Department of Fisheries and Oceans
Government of Canada
Sidney, B. C.

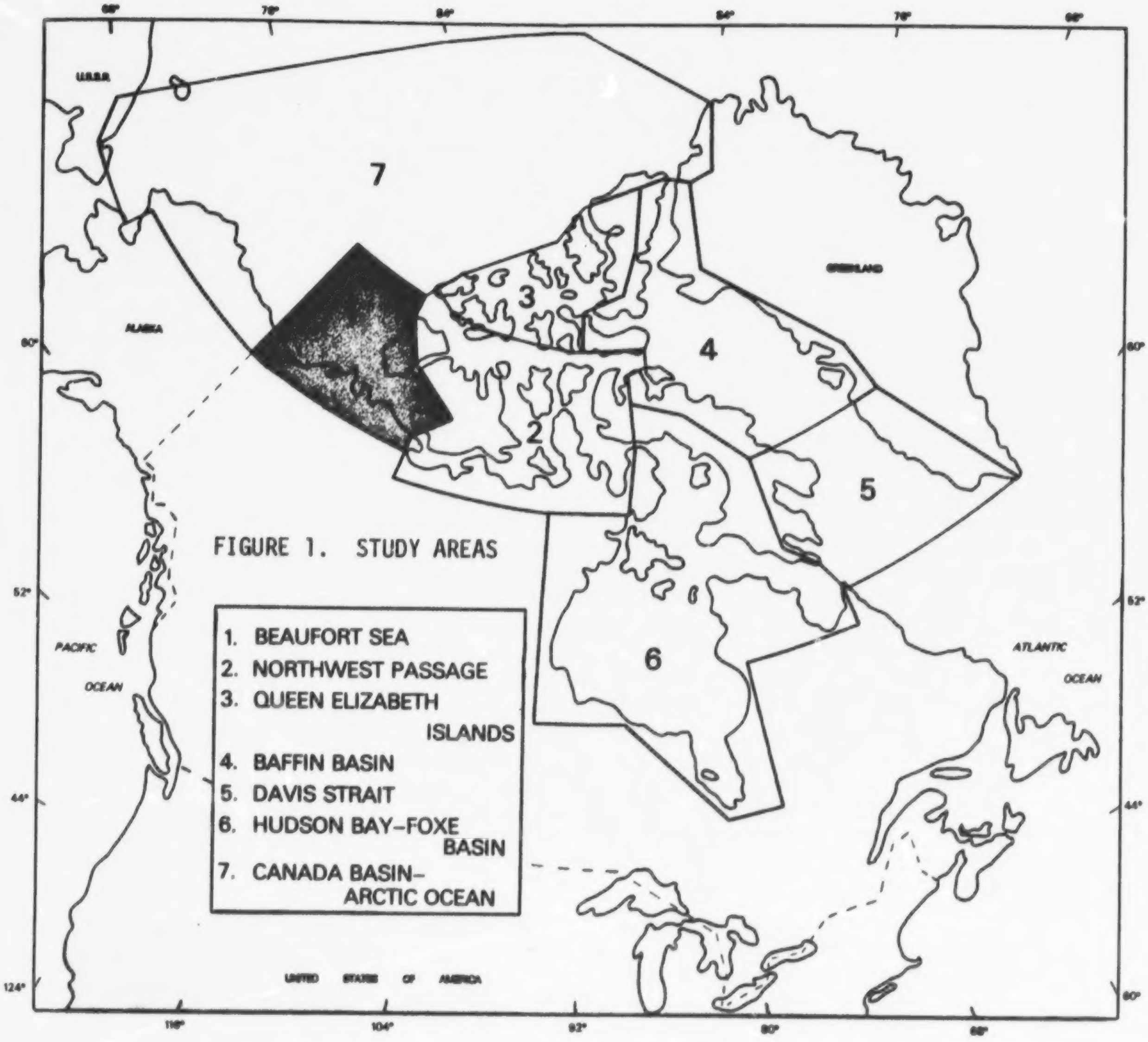

U.S.S.R.
7
3
GREENLAND
ALASKA
4
2
5
6
PACIFIC OCEAN
ATLANTIC OCEAN
1. BEAUFORT SEA
2. NORTHWEST PASSAGE
3. QUEEN ELIZABETH ISLANDS
4. BAFFIN BASIN
5. DAVIS STRAIT
6. HUDSON BAY-FOXE BASIN
7. CANADA BASIN-ARCTIC OCEAN
UNITED STATES OF AMERICA
60°
52°
44°
124°
116°
104°
92°
80°
68°

FIGURE 1. STUDY AREAS

ABSTRACT

Since 1980, the Institute of Ocean Sciences, Sidney, B.C. has embarked on the Arctic Data Compilation and Appraisal Program, by searching, compiling, evaluating, publishing and archiving the complete documentation for existing oceanographic data from the Beaufort Sea and other arctic regions. The findings are summarized in a series of regional data catalogues which use tables, maps and listings to inform the users about 'who collected and analyzed what and where, how and why, and how well.' This information about the historical data is necessary before answering or even posing, questions of impact assessment, research monitoring and regional planning. The paper briefly outlines the steps and status of the Program.

1. INTRODUCTION

In terms of oceanographic research, most of the past Canadian Beaufort Experience spans only a period of 30 to 50 years. For physical oceanographers, some temperature and salinity data were collected in 1935 by the Royal Canadian Mounted Police aboard the vessel St. Roche. The United States Navy first provided marine chemists on the U.S.S. Burton Island with oxygen data. Although the British Admiralty, American Museum of Natural History and the New York Zoological Society kept biological records and whale harvest logs or conducted hunter interviews and vessel watches as early as 1848, the initial Canadian research on whale distribution was conducted by the Arctic Institute of North America, the Arctic Biological Station and the Canadian Wildlife Service in the early 1950's. Similarly, systematic fish and benthos data was not collected until after World War II, primarily by the Arctic Biological Station operating from the vessels Calanus and Salvelinus.

The nature and scope of oceanographic research activity has increased suddenly over the past ten to fifteen years, with the advent of oil and gas exploration on the Mackenzie Shelf. For example, almost 50% of the cruises and expeditions collecting ocean temperature and salinity data were conducted in the six years (1974-1980) that Dome Petroleum drilled many of the total exploratory wells spudded to date. In concert with this increase in the quantity of oceanographic information, there has been a rapid improvement in the quality of these data. Until very recently, oceanographic instrumentation in marine sciences was crude in comparison with that in other sciences. For example, sampling devices designed in the early years of this century by men such as Norwegian arctic scientist/explorer Fridtjof Nansen (1961-1940) are still in common use. Things have changed most rapidly in the physical and chemical sciences, where techniques of accurate measurement using electronic equipment and refined analytical procedures are often as sophisticated as in any contemporary science. Such trends are directly reflected in the data themselves, in terms of their reliability and usefulness.

Our knowledge of the Beaufort, although somewhat better than many Canadian arctic waters, has been delayed by many factors, not least of which is the extraordinary costs of gathering scientific data. Logistics alone in remote, ice-covered waters during the annual eight month dark freeze is a formidable challenge for machine operation and human safety. Since the acquisition of new marine data is so expensive and somewhat risky and since most scientists rely on comparative information on areas and time frames other than those encompassed by their own field work, it is essential that systems of data compilation and exchange be established. In the late 1950's, a few national and international data centres were founded with the purpose of collecting data from numerous oceans, including the Beaufort Sea. In 1964, the Canadian Oceanographic Data Centre was established in Ottawa to process acquired data into standard form and storing them for retrieval and exchange. Other data centres for geological and meteorological information were set up. Subsequently, all marine-related sciences are now being amalgamated into the Canadian government's Marine Environmental Data Service (MEDS).

Although data centres were originally set up to answer the needs of scientists, new demands for the exploitation of the sea and its resources brought two more user groups: the petroleum industry and government managers. New lines or changed emphasis of scientific investigation were launched into sea ice, ocean circulation, fish and mammal biology, usually focussed on engineering design, operational safety or environmental protection. These changes posed new problems; not only was there a flood of newly-generated data, but much of it went into private banks or accumulated in laboratories and on desks, and was not published or never forwarded to MEDS. Other data that did go to MEDS were often incomplete, lacked documentation or arrived in a format unusable by the archivists. In part, to rectify this situation, the Institute of Ocean Sciences, Sidney, British Columbia instigated the Arctic Marine Data Compilation and Appraisal Program. The Program will be discussed as five phases listed below:

- the SEARCH for all data sources;
- the COMPILATION of all data set documentation;
- the APPRAISAL of detailed data descriptions;
- the PUBLICATION of catalogues; and
- the development of a computer DATABASE.

2. THE PROGRAM

In the management and exploitation of the Beaufort Sea by government, industry and the public, scientific knowledge of the arctic ocean is sought or demanded. Today hundreds of ocean data clients such as marine engineers, offshore regulators, regional planners, impact assessors, policy makers, and special interest groups may want to examine the data themselves. More often, they want others with good credentials to provide an honest, justified and relevant translation of these data into things called ocean dumping permits, environmental operating conditions, proposed marine park boundaries, oilspill trajectory models, wildlife impact predictions, and so on. Inevitably, these examinations and translations give rise to annotated bibliographies, regional atlases, and sensitivity map folios which attempt to provide a common benchmark of the state-of-knowledge. Unfortunately, because of shortage of time, money and/or interest, the input data are seldom scrutinized for their reliability, utility, and completeness before incorporation into these inherently weak and sometimes misleading management tools. One must remember that today's particular application for these historic data often bears little or no resemblance to the original research objectives and hypotheses.

In 1980, the Institute of Ocean Sciences began to methodically compile and carefully appraise the existing ocean data in the Beaufort Sea and other arctic regions (Figure 2). The job of locating, scrutinizing, compiling, cataloguing, and eventually judging the suitability and sufficiency of these data is very tedious, somewhat expensive and professionally challenging. The Program is funded primarily by the Department of Fisheries and Oceans with contributions from other government agencies (Department

OCEAN INFORMATION & DATA SERVICES PROGRAM

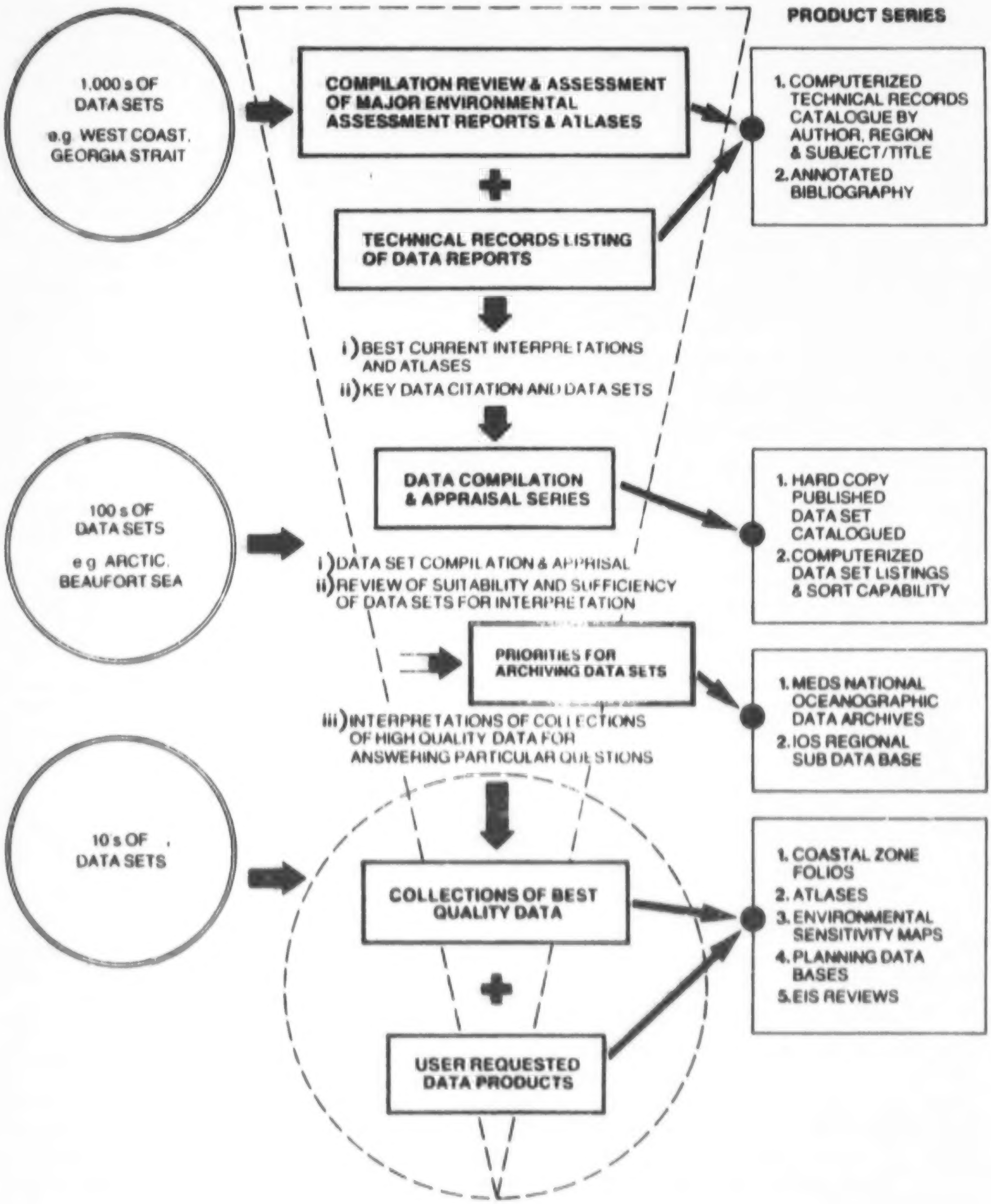

PRODUCT SERIES
1,000 s OF DATA SETS
e.g. WEST COAST, GEORGIA STRAIT
COMPILATION REVIEW & ASSESSMENT OF MAJOR ENVIRONMENTAL ASSESSMENT REPORTS & ATLASES
1. COMPUTERIZED TECHNICAL RECORDS CATALOGUE BY AUTHOR, REGION & SUBJECT/TITLE
2. ANNOTATED BIBLIOGRAPHY
TECHNICAL RECORDS LISTING OF DATA REPORTS
i) BEST CURRENT INTERPRETATIONS AND ATLASES
ii) KEY DATA CITATION AND DATA SETS
DATA COMPILATION & APPRAISAL SERIES
100 s OF DATA SETS
e.g. ARCTIC, BEAUFORT SEA
1. HARD COPY PUBLISHED DATA SET CATALOGUED
2. COMPUTERIZED DATA SET LISTINGS & SORT CAPABILITY
i) DATA SET COMPILATION & APPRISAL
ii) REVIEW OF SUITABILITY AND SUFFICIENCY OF DATA SETS FOR INTERPRETATION
PRIORITIES FOR ARCHIVING DATA SETS
1. MEDS NATIONAL OCEANOGRAPHIC DATA ARCHIVES
2. IOS REGIONAL SUB DATA BASE
iii) INTERPRETATIONS OF COLLECTIONS OF HIGH QUALITY DATA FOR ANSWERING PARTICULAR QUESTIONS
10 s OF DATA SETS
COLLECTIONS OF BEST QUALITY DATA
1. COASTAL ZONE FOLIOS
2. ATLASES
3. ENVIRONMENTAL SENSITIVITY MAPS
4. PLANNING DATA BASES
5. EIS REVIEWS
USER REQUESTED DATA PRODUCTS

FIGURE 2.

of Indian Affairs and Northern Development, and Department of Energy, Mines and Resources) and marine industries such as Dome Petroleum Ltd. To date, the expenditures approach 500 thousand dollars. The bulk of the work is carried out by expert oceanographic consultants such as Arctic Sciences Ltd., Arctic Laboratories Ltd., LGL Consultants Ltd., E.V.S. Consultants Ltd., MacLaren Plansearch Ltd. and others.

3. THE SEARCH

Both for convenience of contract management and obvious marine geography, we divided the Canadian Arctic into six broad regions: Beaufort Sea, Northwest Passage, Queen Elizabeth Islands, Baffin Bay, Davis Strait, Hudson Bay, and the Canada Basin. The latter region encompasses the Arctic Ocean including American waters such as the Chukchi Sea (Figure 1). For each broad region, beginning with the Beaufort Sea, experienced and qualified oceanographers are attempting to expose all existing data, discipline by discipline. The physical oceanographic data has proven to be relatively easy; there are few parameters (currents, temperature, salinity and water levels) of prime importance to water column processes. Data status is somewhat standard (e.g. detailed station listings, magnetic tapes from common instruments). The search challenge increases significantly for the chemical oceanographer, confronted by over one hundred chemical parameters (nutrients, oxygen, trace metals, hydrocarbons, turbidity, chlorinated hydrocarbons e.g. pesticides) found in the sediments, water column, sea ice and animal tissue. Further complexity was added when considering the hundreds of diverse techniques for chemical sampling, storage and analysis.

However, both these disciplines pale somewhat in level of difficulty when compared to the slothing demands of finding missing biological oceanographic data. The task is subdivided by common species groupings; to date, this includes whales (primarily bowhead and white whales), marine fishes including anadromous species, and marine zoobenthos (including microscopic foraminifera). Most of the existing data are measurements of abundance, distribution, morphology and behavior; although biologists observe, catch, kill and process the specimens in hundreds of ways, not usually the same way twice. The greatest obstacle to any inventory of whale, fish or benthos data is the large amount of unpublished or unanalyzed data, some of which is proprietary or otherwise treasured, others of which are messy and difficult to decipher without careful scrutiny (a significant funding requirement in itself).

The Program's search begins with data, not conclusions and interpretations. More specifically, the search is for the data's complete documentation and description including the study area and period investigator, methods and so on. Our preoccupation with 'documentation first, data second' is based on the premise that the data may or may not be reliable or useful, but this cannot be judged without their accompanying detailed instructions. The Program's oceanographers initially combed the published, reported and archived sources of data--national and international, public and proprietary.

They continued on to examine miscellaneous magnetic tapes, field notes, record sheets to determine both the status of the data. Personal letters, international telephone calls, questionnaires and word of mouth are employed when necessary. In a sentence, the search task is to discover who working for whom measured what, and exactly where, when and how was this achieved.

4. THE COMPILATION

The search for Beaufort oceanographic data has led to the inventory and organization of 'what is known' about several hundred data sets (a data set is defined as data measured by a single expedition and collected in a uniform manner). Specific numbers of data sets compiled to 1982 are as follows:

-- physical oceanography	127
-- chemical oceanography	107
-- whales	111
-- fishes	49
-- zoobenthos	88

A common format and approach for the compilation was jointly designed by the Institute scientists, technical advisors and oceanographic consultants. The combined use of summary tables, from general to specific, and map plots of all sampling stations and transects provide the basis of compilation. In all inventories, the first table is somewhat standardized and provides the reader, at a glance, with a summarized chronological description of each data set (collecting agency, period of measurements, quantity measured, instruments or methods used, estimate of instrument precision/accuracy, specific area of study, any concurrent measurements taken, and source/reference). We have assigned unique identification numbers to each data set allowing easy cross-reference within and between disciplines. For the more interested and qualified users, there are complete station listings (latitudes, longitudes, hour and day sampling, depth of instrument, size of net mesh, etc.) In addition, some miscellaneous comments and clarifications about each data set are allowed, since any standard compilation format does not always permit adequate scope of technical discussion.

The plotting maps are also standardized, having limited but tasteful choices of scale (1:250,000 and 1:500,000) and coverage. This permits the user to easily compare the station or survey density between data sets and disciplines.

The compilation includes a complete listing of all prime references and some secondary references which cite the data. If the data are unpublished or restricted, the names and addresses of personal or company contacts are given.

The complete archiving and retrieval of the data themselves is not attempted. All data is forwarded to MEDS for this eventual processing. However, most documents and reports which are assembled during the compilation are catalogued and shelved at the Institute's Technical Records Library.

5. THE APPRAISAL

The appraisal step of the Program is intended to provide users of existing data with a simple, objective indication of the level of confidence for each data set measurement, based on the recorded history from collection to final analysis. The appraisal offers a measure of the ultimate believability of the findings and its suitability for comparison with other data sets. Again, the emphasis is on the available documentation describing the specifics of collection and analysis, sample storage and preservation, precision and accuracy, and especially the investigator's own estimate of its reliability and utility. (In some exceptions, the actual data such as bottle cast samples of temperature and salinity were checked using the criteria of expected ranges.) The Program appraisers have briefly described, in laymen's terms, the most common techniques and strategies of field research and laboratory analysis. They outline the inherent limitations and operational frustrations in a manner which clearly argues the value of detailed documentation, and educates the data users to employ the data quality criteria in judging suspicions or problem data.

All major measurement types within each data set is rated by a 5 level rating system, defined as follows:

0: Data are found to be wrong due to known serious deviations from standard methods of collection and analysis, or because necessary documentation no longer exists or never in fact existed.

1: Data are suspect, because the ill-defined doubts remain after examining reported but incomplete documentation.

2: Data could not be appraised, because documentation (which may or may not exist) was not examined.

3: Data are internally consistent (i.e. within the data set) but comparison with other data sets may pose problems in terms of precision.

4: Data are internally consistent and are sufficiently standardized, or tied to a reference, that comparison with similarly-related data should be possible.

This rating system serves only as a guide, and not an absolute statement of data quality. It is only one of several ways to represent the quality of acquired oceanographic data. The ideal rating system would use only objective criteria, which we attempted for in this Program. However, this is not always possible because of the lack of standard procedures and equipment in use, and because of the significant change in philosophy and techniques for collection and analysis in recent years. Consequently a certain subjectivity is inherent in the appraisal. Any given system for objective data quality appraisal is almost doomed to fail as soon as it is chosen.

Since the discretion of the appraiser is often warranted, we employ respected and qualified oceanographers who are familiar with the region and previously had used much of the historic data. Unfortunately, they are often frustrated or stumped by absent or vague details of the data history; additional clarifications cannot be obtained even from the originating agency and principal investigator. For example, 40 to 65% of the data sets appraised in the physical and chemical inventories were assigned 1 and 2 ratings respectively. In fact, it is disheartening to learn that only 15% of either physical or chemical data sets warrant a top mark 4 rating. To quote one appraiser, "It is obvious in many cases (and strongly suspected in others) that although most of the heavy metal data obtained for the Beaufort Sea were collected during the past eight years, the techniques used and level of awareness are most characteristic of those used 40 or more years ago. Viewed as a whole, therefore, the quality of heavy metal data for Beaufort Sea sea water is probably very low and the data little more than collections of random numbers" (Thomas et al., 1982, p. 26).

6. THE PUBLISHED CATALOGUES

The Program reports its inventory and appraisal efforts by the preparation and distribution of 'Sears' type catalogues, which serve as indexes or guides to the existing oceanographic data. Although comprehensive and detailed, these 200 to 300 page catalogues are relatively easy to use because of their standard format, systematic tables and atlas-like maps. Again, we must emphasize that these catalogues do not contain the data themselves, much the same way the 'Sears' catalogue does not offer the actual merchandise between its covers. Instead, the data catalogue user is hopefully treated to enough information about all relevant data to judge for himself/herself, the likely success of answering any particular question, whether pertaining to research monitoring, environmental impact, planning options, and so on. For example, based on the catalogue's graphic evidence of sparse data coverage and ill-defined doubts by qualified oceanographers about the handful of relevant data sets which do exist, one might decide that it is foolish to ask a question, however good, for which a thousand wisemen cannot provide a satisfactory answer.

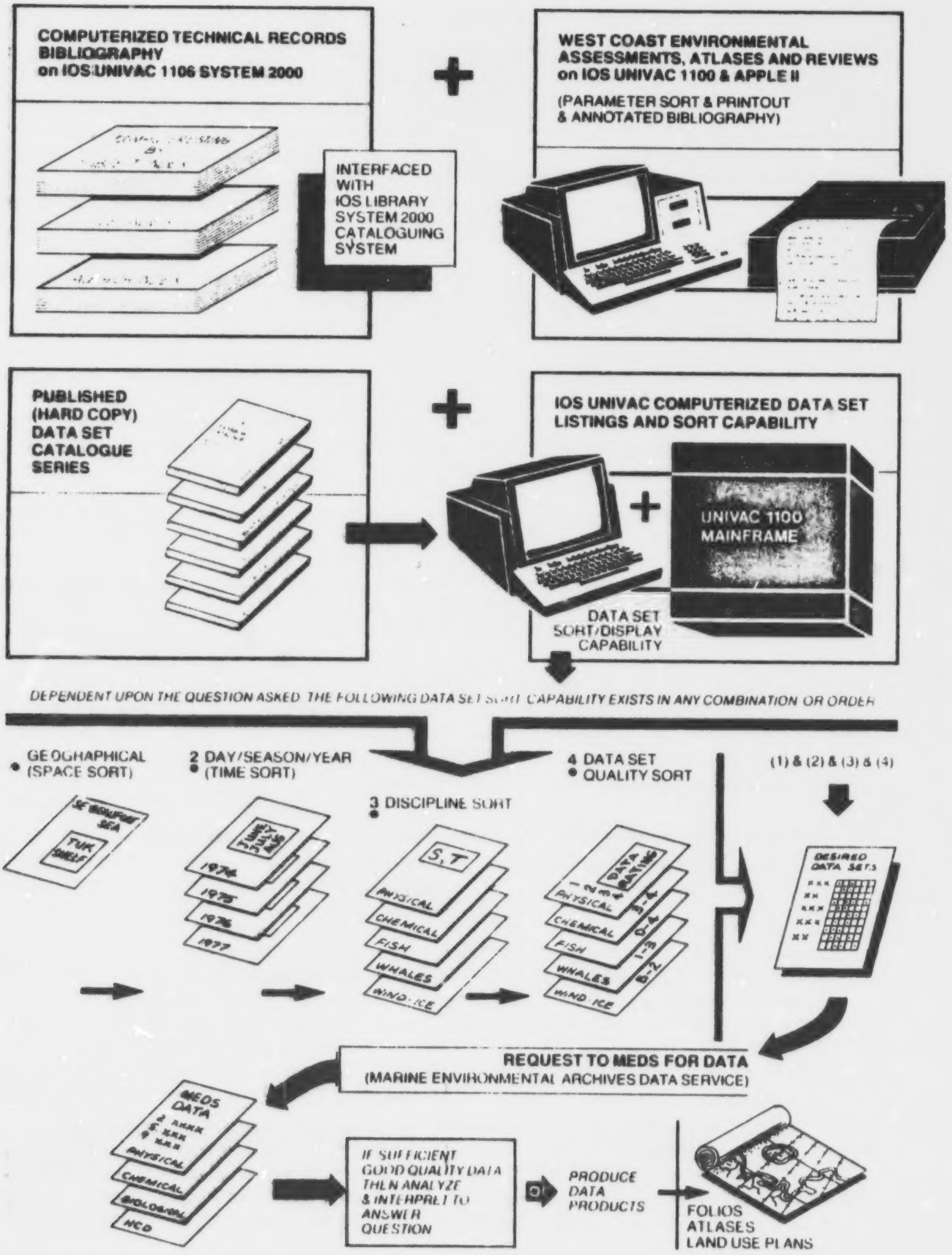
The catalogues also provide a brief, regional overview of major trends and area-specific pecularities of the historic data; this assists the unfamiliar user to better appreciate some background for the state-of-the-knowledge, such as the tag-along, research-of-opportunity approach using defence expeditions in the 1950s or the unique advantages of drifting pack ice for a sampling platform.

Some catalogues identify the existence of two or more data sets independently collected at the same time within the region. These, if combined, would provide a near-synoptic coverage over a relatively large area or allow comparison of simultaneous oceanographic processes. For example, in eight different years between 1951 and 1977 in the Beaufort Sea, possibilities of such combinations exist in the temperature-salinity data collected during the open water season. Further, some catalogues outline repeated measurements by independent scientists in the same area, thus providing a future opportunity to analyze for long-term trends or to estimate year-to-year variability. One example of such an extended time series is the twenty-three data sets of summer, physical oceanographic measurements on the Tuktoyaktuk Shelf between 1952 and 1980.

The data catalogues are jointly prepared by the consultant oceanographers under contract, government research investigators (usually designed as a scientific authority for peer review) and technical personnel of the Ocean Information Division, Institute of Ocean Sciences. The catalogues are published in the new Fisheries and Oceans Canada series called

'Canadian Data Reports of Hydrography and Ocean Sciences.' To date, September 1983, five data set catalogues are published, two of which pertain to Beaufort Sea oceanography. An additional six catalogues are in various stages of preparation, as outlined below:

Region/ Subject	Principal Consultants/ Agency	Status
1. Beaufort Sea		
- Physical oceanography: currents, salinity, etc.	Arctic Sciences Ltd. Sidney, B.C.	published (1982)
- Chemical oceanography: nutrients, metals, etc.	Arctic Laboratories Ltd. Sidney, B.C.	published (1982)
- Biological oceanography: bowhead and white whales	LGL Ltd. Sidney, B.C.	2nd draft
- Biological oceanopgrahy: marine fishes	Freshwater Institute Winnipeg, Manitoba	2nd draft
- Biological oceanography: marine zoobenthos	Institute of Ocean Sciences Sidney, B.C.	2nd draft
2. Northwest Passage		
- Physical oceanography: current, salinity, etc.	Arctic Sciences Ltd. Sidney, B.C.	published (1983)
- Chemical oceanography: nutrients, metals, etc.	Arctic Laboratories Ltd. Sidney, B.C.	published (1983)
3. Queen Elizabeth Islands		
- Physical oceanography: currents, salinity, etc.	Arctic Sciences Ltd. Sidney, B.C.	final draft
4. Baffin Bay		
- Physical oceanography: currents, salinity, etc.	Arctic Sciences Ltd. Sidney, B.C.	published (1983)
7. Canada Basin		
- Physical oceanography: currents, salinity, etc.	Arctic Sciences Ltd. Sidney, B.C.	commenced August 1983
- Chemical oceanography: nutrients, metals, etc.	Arctic Laboratories Ltd. Sidney, B.C.	commenced August 1983


COMPUTERIZED TECHNICAL RECORDS BIBLIOGRAPHY on IOS UNIVAC 1106 SYSTEM 2000
+
WEST COAST ENVIRONMENTAL ASSESSMENTS, ATLASES AND REVIEWS on IOS UNIVAC 1100 & APPLE II
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INTERFACED WITH IOS LIBRARY SYSTEM 2000 CATALOGUING SYSTEM
PUBLISHED (HARD COPY) DATA SET CATALOGUE SERIES
+
IOS UNIVAC COMPUTERIZED DATA SET LISTINGS AND SORT CAPABILITY
+
UNIVAC 1100 MAINFRAME
DATA SET SORT/DISPLAY CAPABILITY
DEPENDENT UPON THE QUESTION ASKED THE FOLLOWING DATA SET SORT CAPABILITY EXISTS IN ANY COMBINATION OR ORDER
• GEOGRAPHICAL (SPACE SORT)
BEAUFORT SEA
TUK SHELF
2 • DAY/SEASON/YEAR (TIME SORT)
JUNE JULY AUG
1974
1975
1976
1977
3 • DISCIPLINE SORT
S,T
PHYSICAL
CHEMICAL
FISH
WHALES
WIND ICE
4 • DATA SET QUALITY SORT
DATA RATING
1 2 3 4
PHYSICAL 3-4
CHEMICAL 0-4
FISH 1-3
WHALES 0-2
WIND ICE
(1) & (2) & (3) & (4)
DESIRED DATA SETS
REQUEST TO MEDS FOR DATA
(MARINE ENVIRONMENTAL ARCHIVES DATA SERVICE)
MEDS DATA
PHYSICAL
CHEMICAL
BIOLOGICAL
NCD
IF SUFFICIENT GOOD QUALITY DATA THEN ANALYZE & INTERPRET TO ANSWER QUESTION
PRODUCE DATA PRODUCTS
FOLIOS
ATLASES
LAND USE PLANS

FIGURE 3.

Copies of the published catalogues are mailed without charge on request to the Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, B.C. V8L 4B2.

It is our intention to publish supplementary catalogues in the next three to five years, with updated compilation and appraisal of new data collected since 1982.

THE DATABASE

As part of the Program, we maintain a computer database of all oceanographic data sets published in the catalogues (Figure 3). Presently, this database is comprised of complete descriptions and station/survey listings of the physical oceanographic data (currents, temperature, etc.) for the western and central Arctic regions. However, this is under expansion to include the chemical and biological oceanography. Unlike the published catalogues, the database can be easily updated as new data becomes available. In addition, the computer sorting ability permits a wide range of cross-referencing searches, in order to quickly converge on the most suitable data sets for the user's particular application.

The Program's database is stored on the Institute's UNIVAC 1100 mainframe computer. The system management software is INTEL's 'System 2000.' Best access to the database is onsite at the Institute. However, outside users who are familiar with System 2000 ACCESS language can link up using the DATAPAC network. For onsite users, we provide a special software package, a series of quering user-menus, to access both the oceanographic database and a map graphics program. This graphics program enables each user to chose maps of any arctic area and to depict the density of ocean data stations or surveys, as sorted for display. The program will operate on graphics terminals which support TEKTRONIX PLOT 10. Output is displayed on a local graphics terminal (TELEVIDEO 950 with graphics) from which hardcopy maps are produced either by a graphics printer (EPSON MX-100) or computer plotter (HEWLETT-PACKARD 7221T).

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Thomas, D.J., R.W. Macdonald, and A.B. Cornford. 1982. Arctic Data Compilation and Appraisal. Volume 2. Beaufort Sea: Chemical Oceanography. Can. Dat. Rep. Hydrogr. Ocean Sci. 5: 243 pp.

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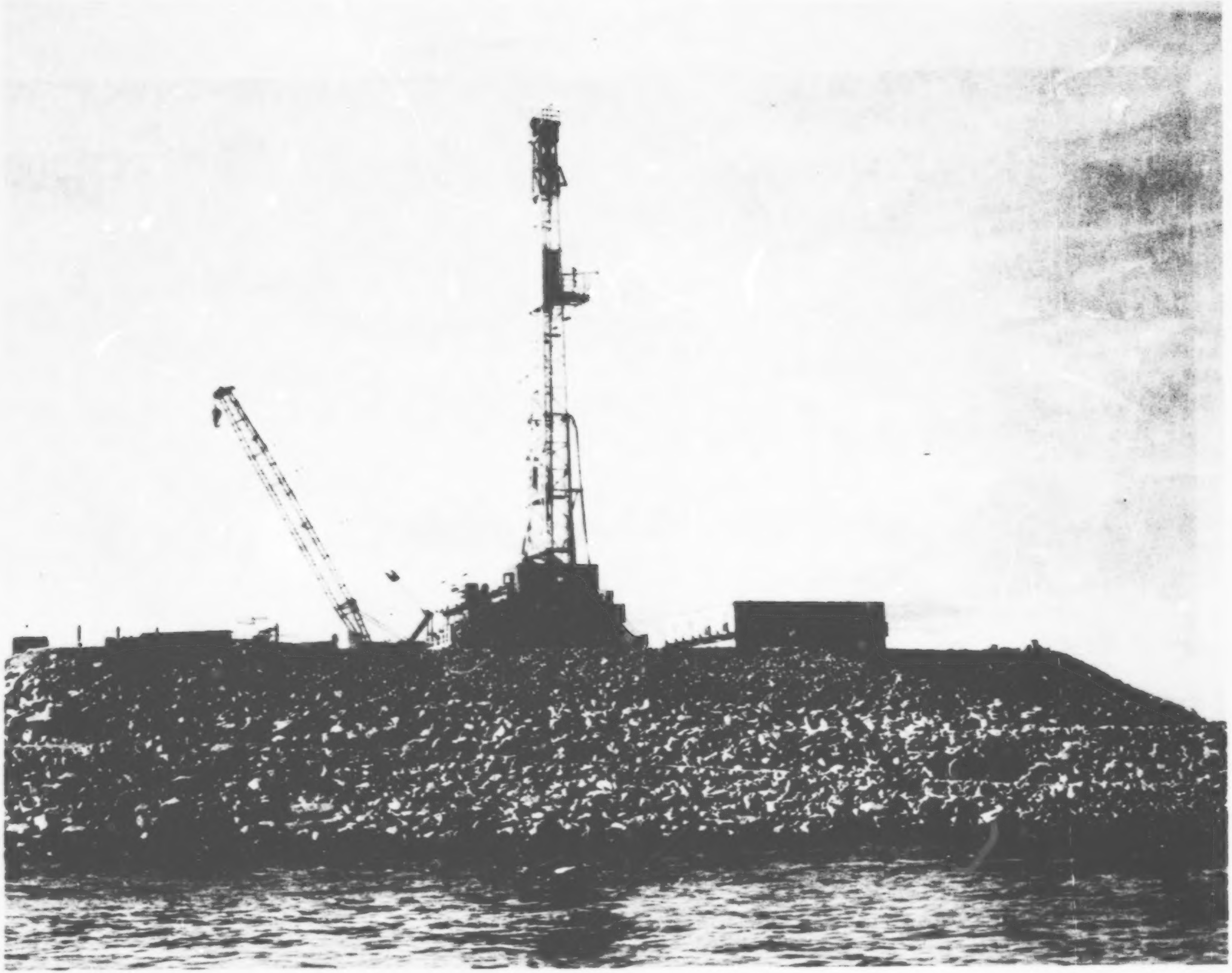
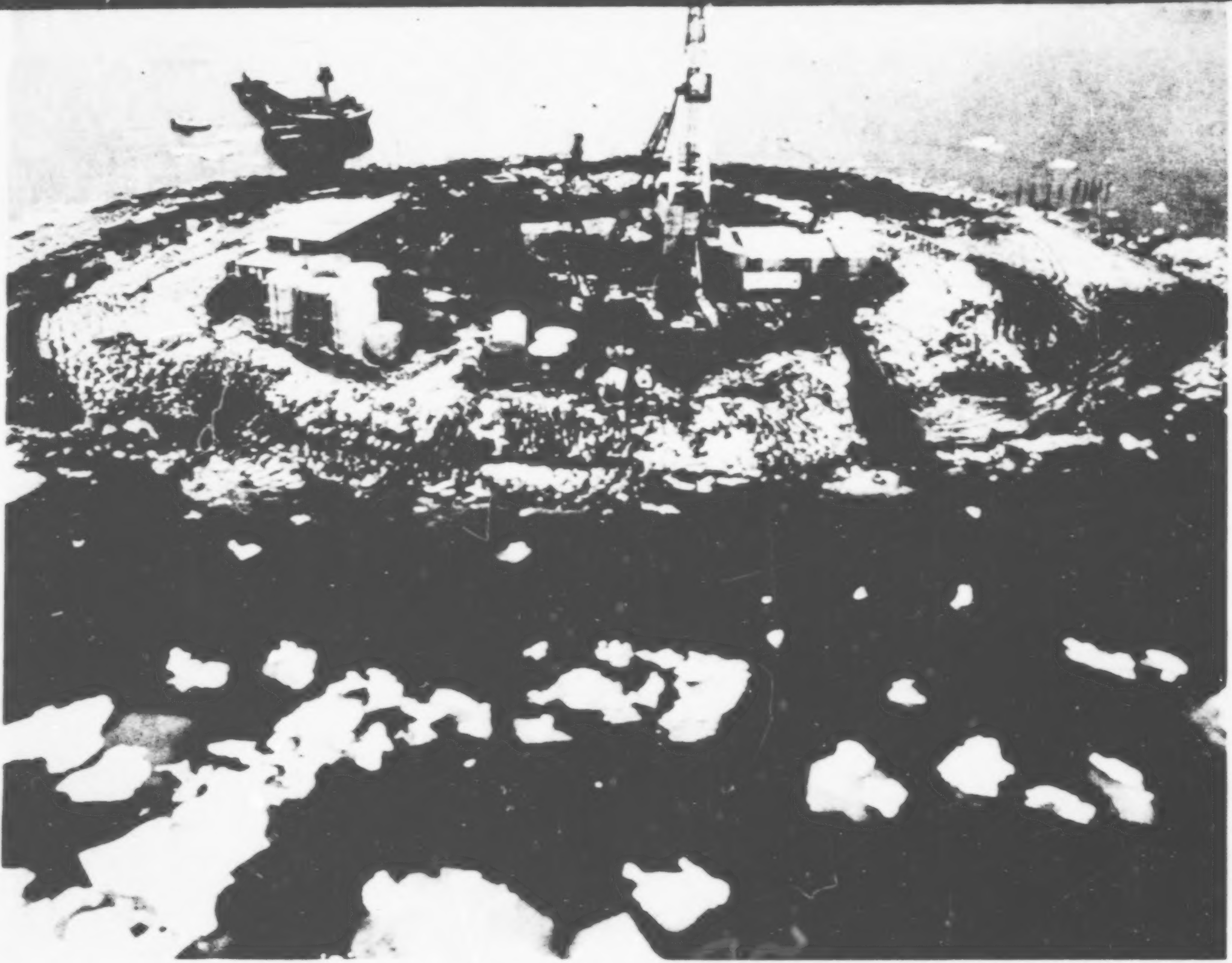
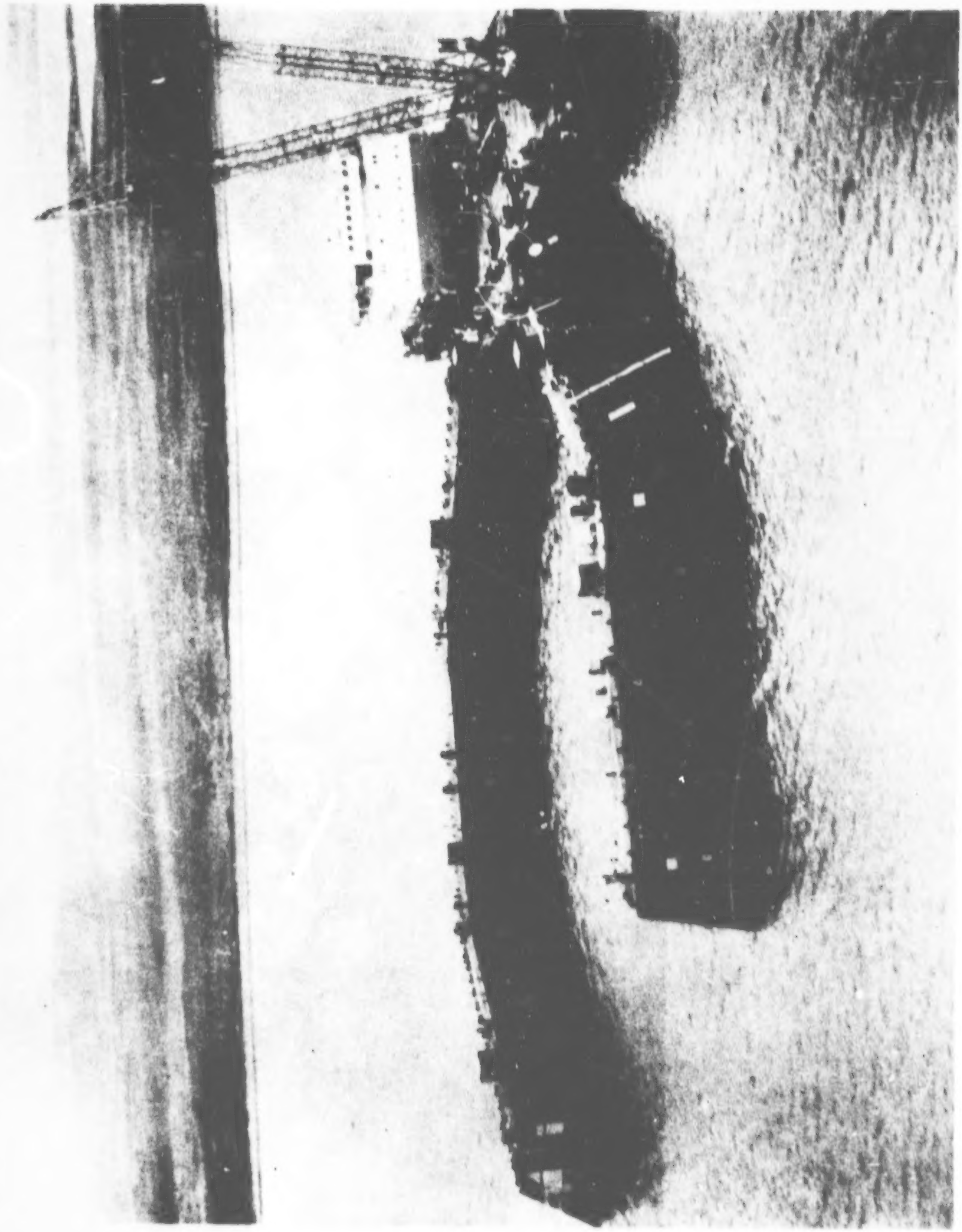


2. Norman Wells - rig atop island in Mackenzie River.

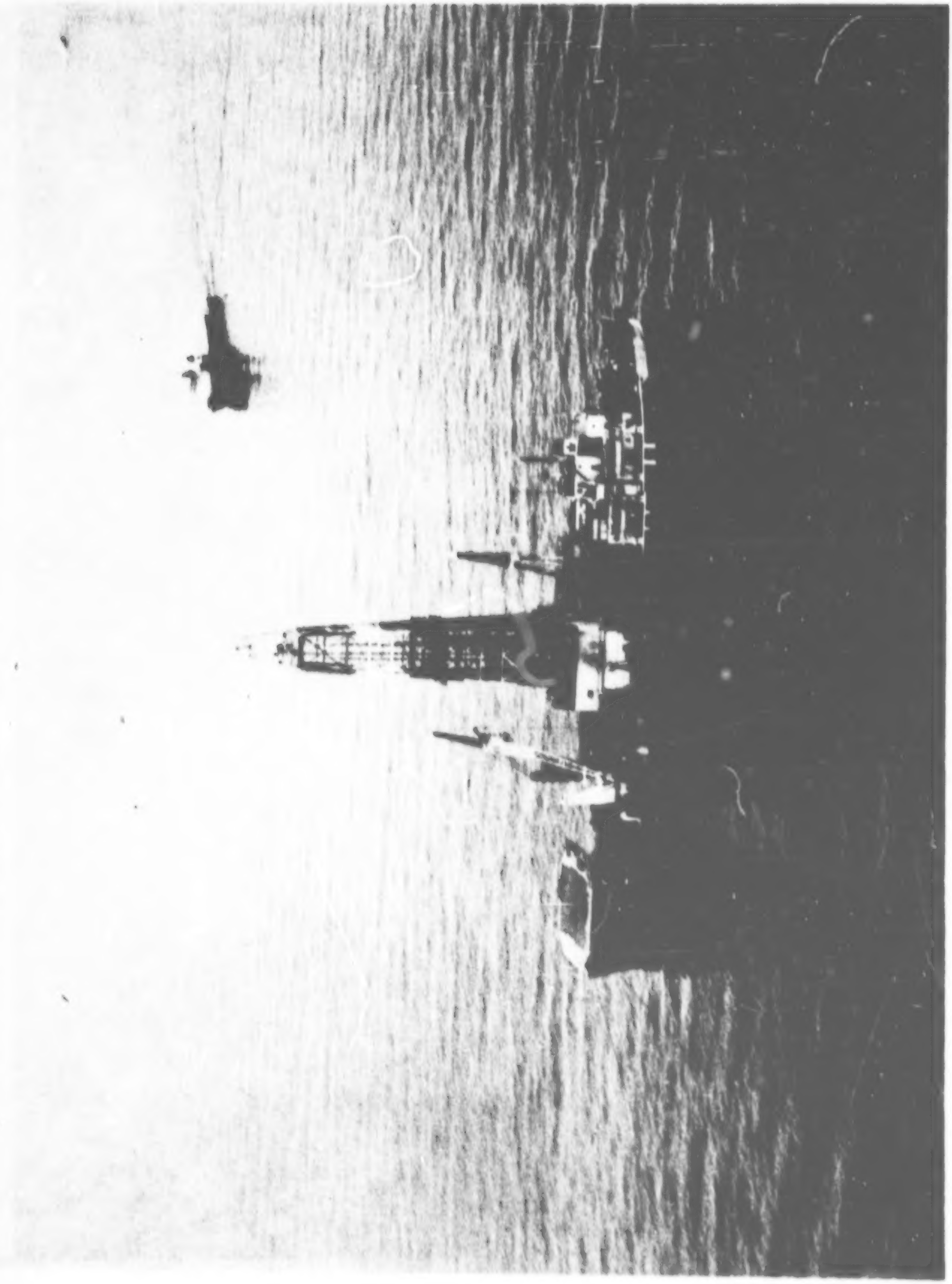


3. Artificial Island, Beaufort Sea.

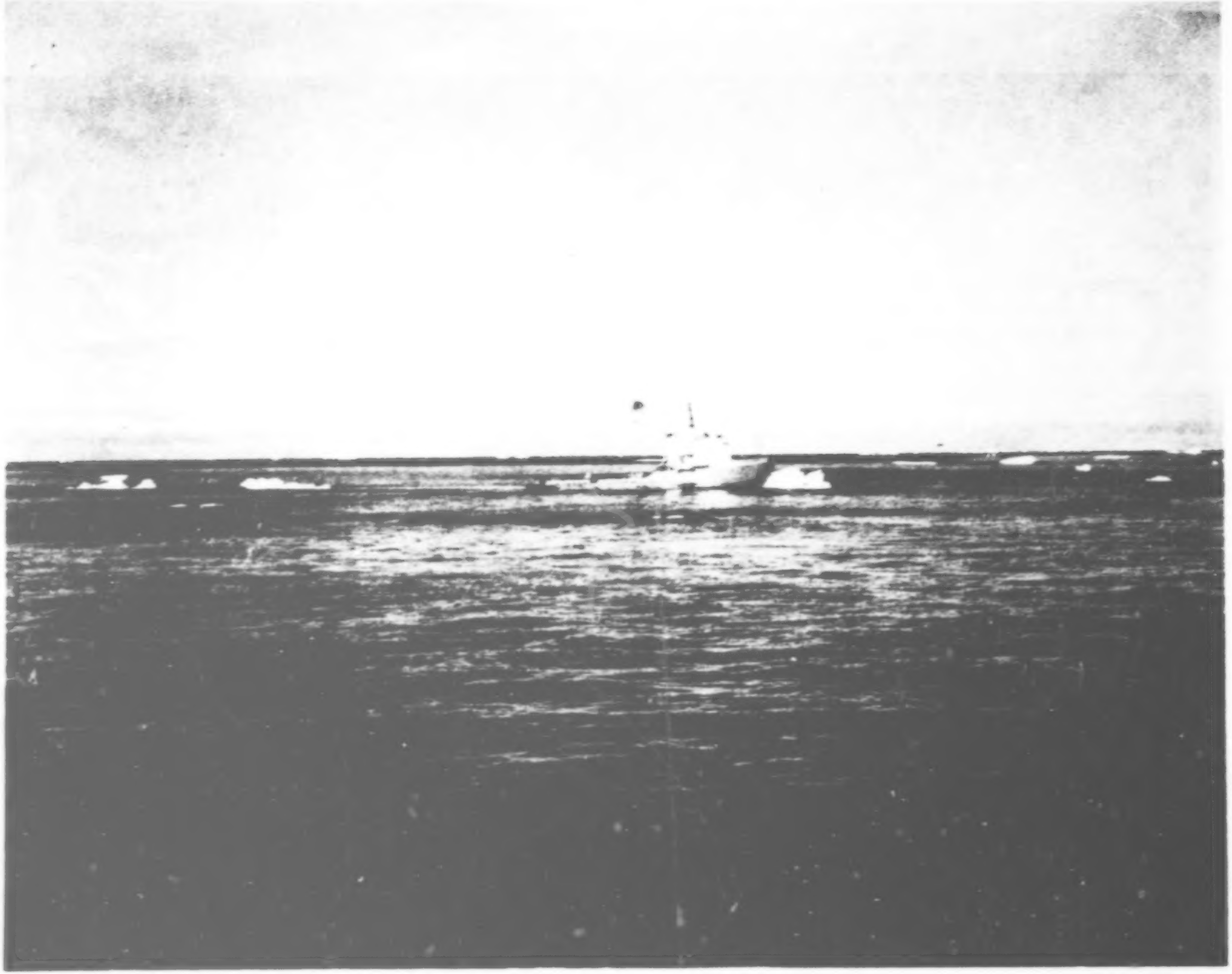


4. Caisson prior to installation on caisson-retained island.

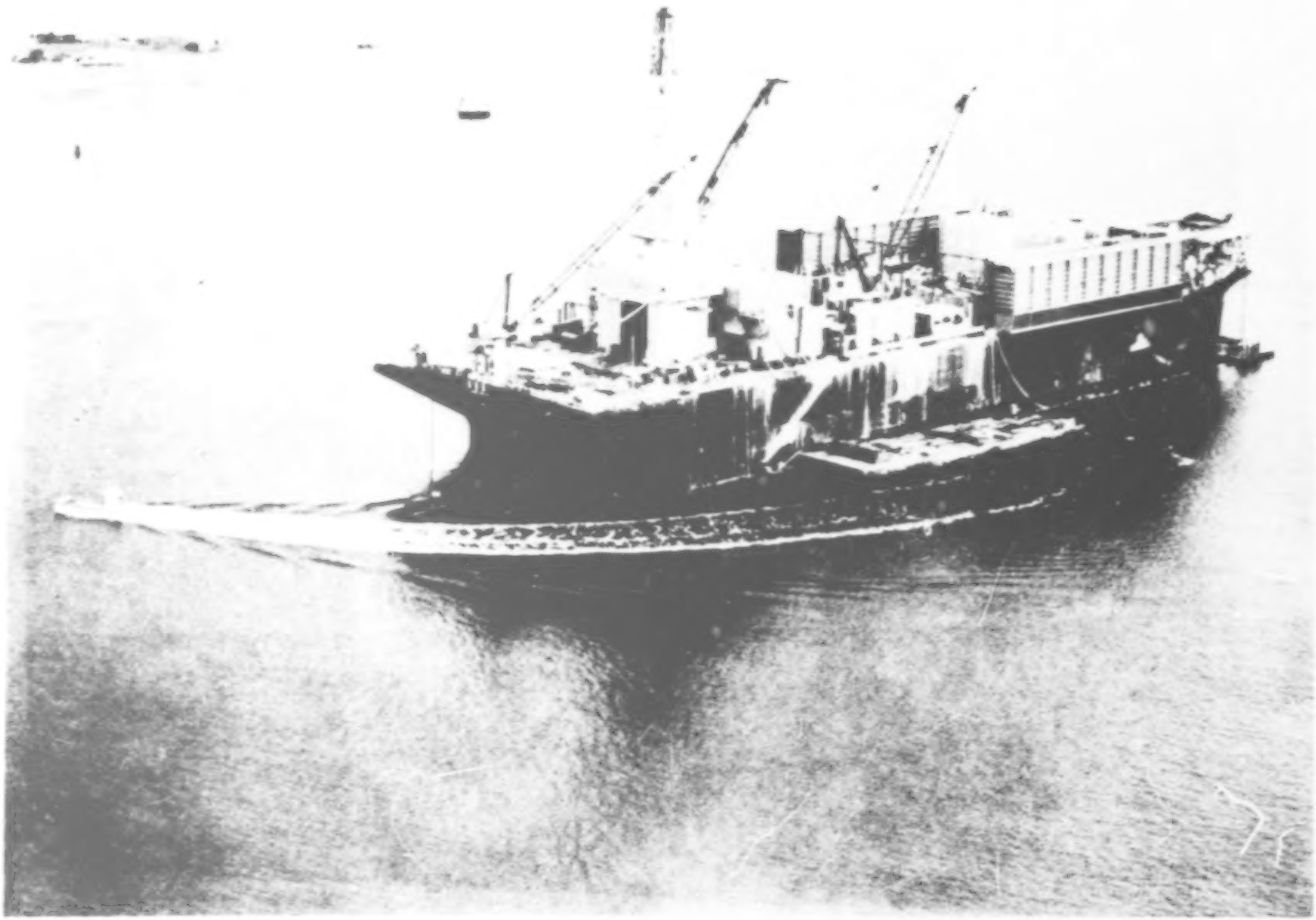
Photo Courtesy Esso Resources



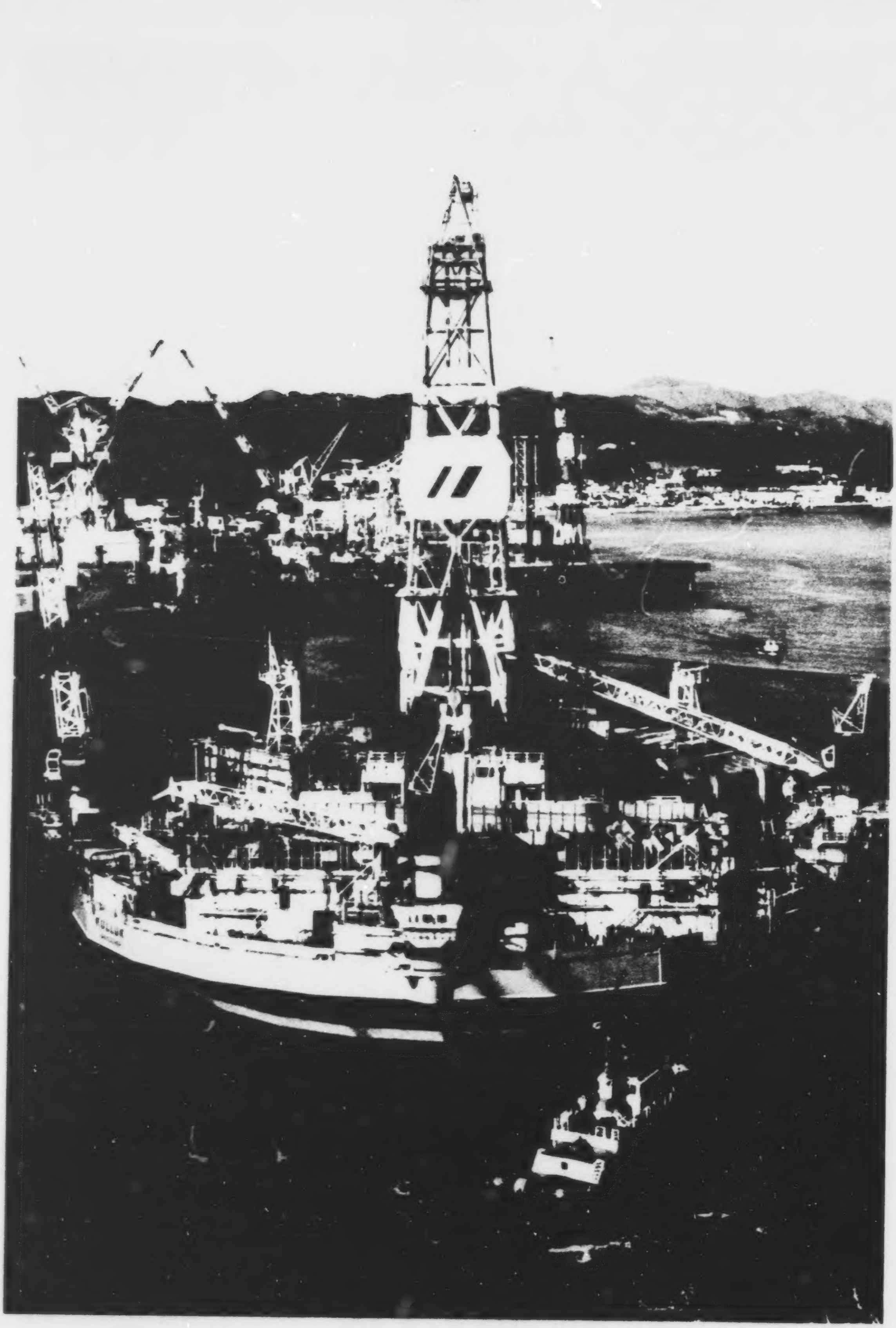
5. Canmar's drillship Explorer in Beaufort Sea.



6. Support vessel moving ice floes away from drillship.



7. The SSDC (semi-submersible drilling caisson), a new concept for drilling wells in ice-covered waters.



Courtesy Gulf Canada Resources

8. 'Kulluk', a conical drilling unit designed for use in the ice-infested waters of the Beaufort Sea.

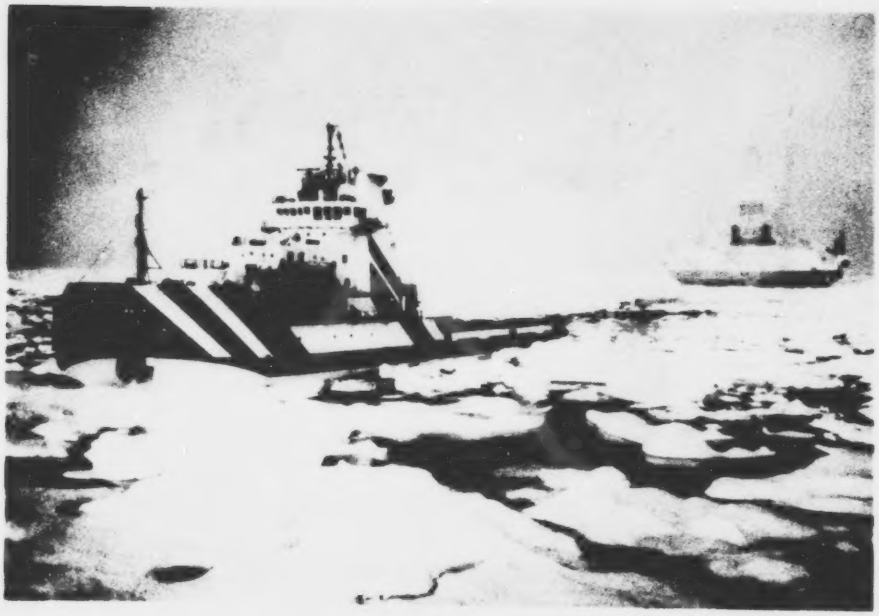


Figure 1-M.V. Ikaluk and the Kulluk

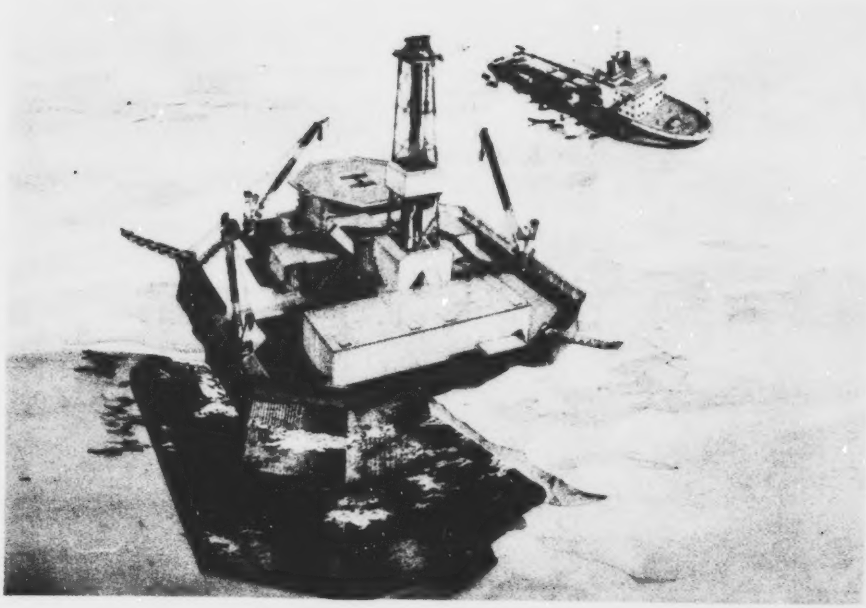


Figure 2-Artists conception of the mobile arctic caisson

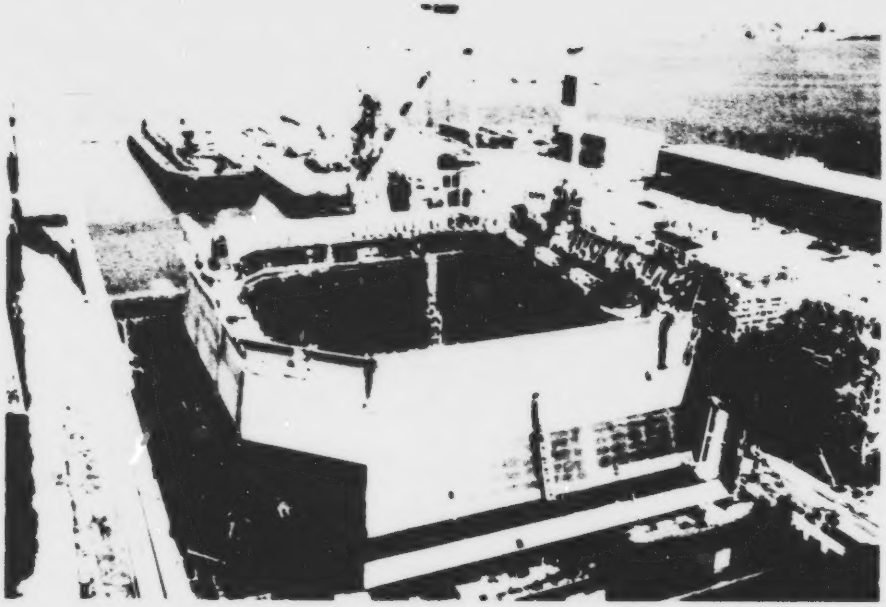


Figure 3-Mobile arctic caisson Molikpaq

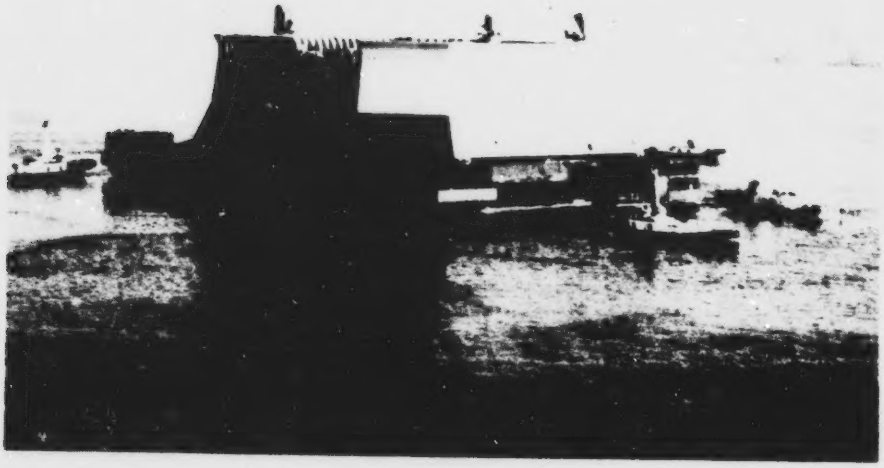


Figure 4-The Molikpaq

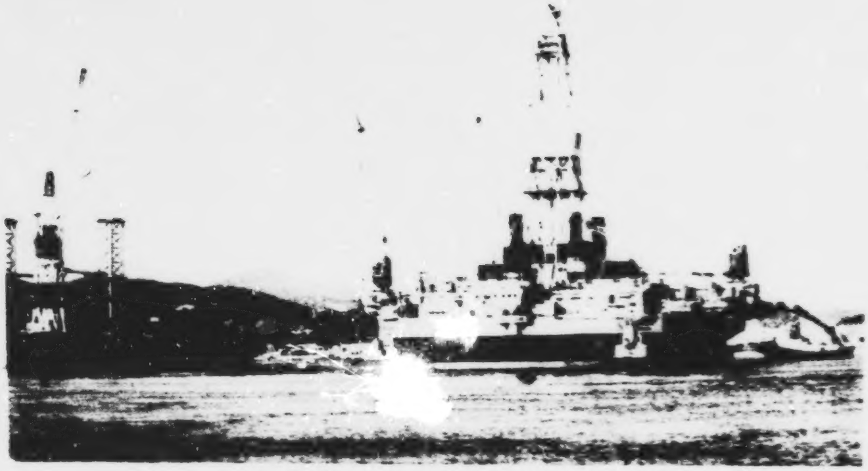


Figure 5-The conical drilling rig "Kulluk"

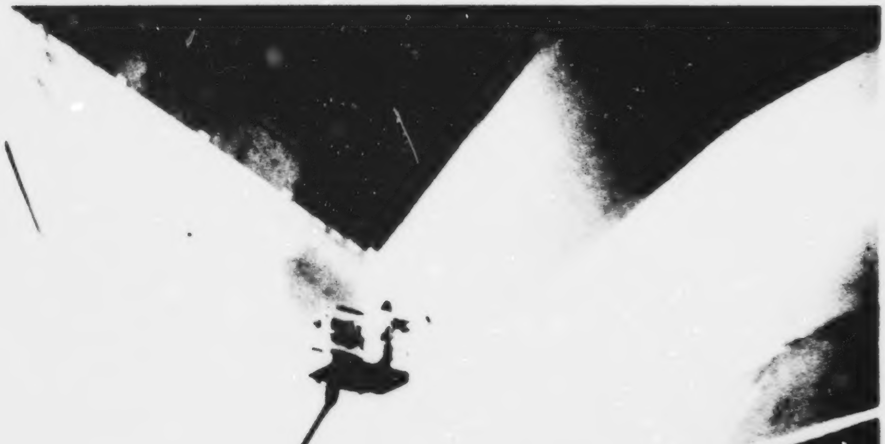


Figure 6-The Kulluk's ice deflecting hull

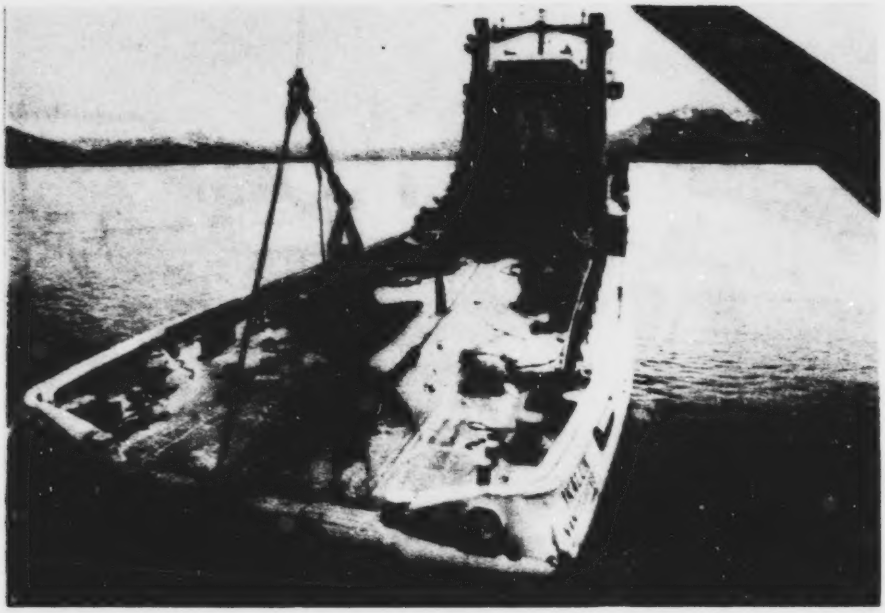
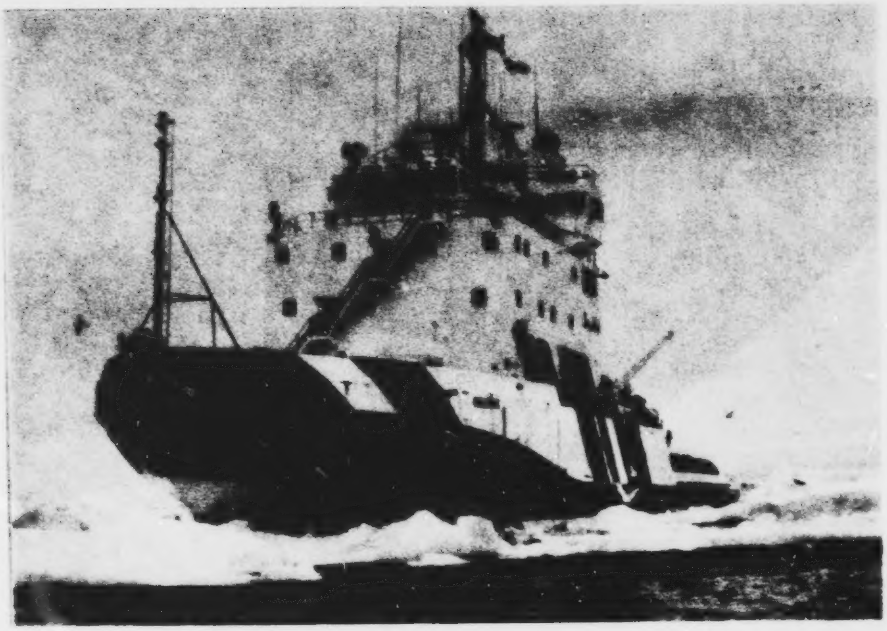


Figure 7-An anchor used to position the Kulluk

Figure 8-The Kulluk in the Beaufort Sea



M.V. "Kalvik"

M.V. "Ikaluk"

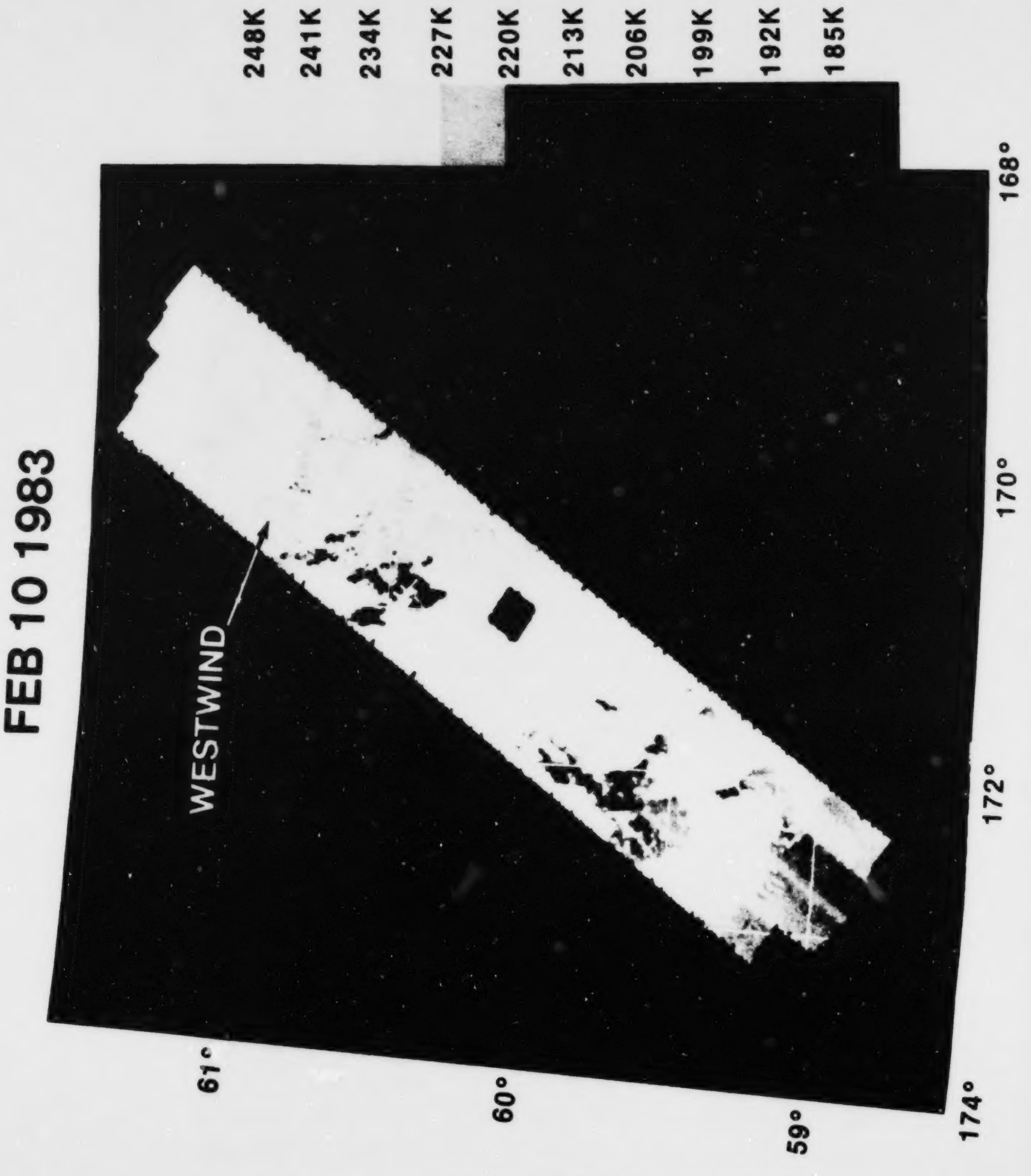

FEB 10 1983
WESTWIND
248K
241K
234K
227K
220K
213K
206K
199K
192K
185K
168°
170°
172°
174°
61°
60°
59°

FIGURE 8 MOSAIC OF HIGH FREQUENCY (92 GHz) AMMS DATA COLLECTED BY THE NASA CV-990

PART THREE

OIL SPILL RESEARCH: CANADIAN AND U.S. PROGRAMMES

Public concern over oil and gas activities in the Arctic centres strongly on the risk of a well blow-out and of an oil spill. At the same time, industry has invested a substantial amount of time, energy and dollars in research oriented at preventing blow-outs and at cleaning up oil spills with the minimum of environmental damage. Much of this research is described in the seven volume Environmental Impact Statement prepared by Dome, Gulf, Esso and their partners for the Beaufort Environmental Assessment Review Process.

Part Three of this book includes reprints which summarize Dome's oil spill R & D in ice-infested waters in the Canadian Beaufort and Alaska operator's programme in the waters off the Alaska North Slope.

ICE IS NICE:

OIL SPILL RESEARCH AND COUNTER MEASURES FOR THE BEAUFORT SEA

Presented by

W.M. PISTRUZAK

Environmental Research Section
Production Development Department
Dome Petroleum Limited
Calgary, Alberta

In the Northwest Territories, just east of where the MacKenzie River enters the Beaufort Sea lies the small Arctic community of Tuktoyaktuk. The nearby "Tuk" base--a hub of activity--is the base camp for Dome Petroleum's offshore drilling operations in the Beaufort Sea.

Dome and its partners have approximately 4.6 million hectares of oil and gas rights on the continental shelf of the Beaufort Sea. The sedimentary formations under these waters are believed to contain up to 7.5 billion cubic metres of recoverable oil--enough to supply Canadians with all their oil needs for at least the next 30 years!

To search for this oil, hundreds of millions of dollars have been spent over the last several years developing and operating drilling systems specially designed for the ice-infested environment of the Beaufort Sea. So far, 14 offshore wells have been drilled using a fleet of ice reinforced drillships owned and operated by the Company's subsidiary, Canadian Marine Drilling Ltd. (Canmar). Included in its fleet is the Kogoriak--a new generation ice-breaker and the first vessel able to operate year-round in the North American Arctic. With supply and drillships, work boats, dredges, barges, fixed-wing aircraft, helicopters and the large shore base at Tuk, the Company's total investment in Arctic drilling facilities exceeds $440 million.

THE MAJOR CONCERN

The Canadian public has always had a special attachment to the Arctic, and is naturally apprehensive about any activity there that might disturb the people or the environment. The major concern is that an oil well blowout might occur and cause tremendous damage. Dome shares this viewpoint and this has been reflected in its on-going activities in the Beaufort.

Fortunately, the chances of a major oil well blowout occurring during off-shore drilling operations are very slim. Specifically, of the thousands of exploratory wells drilled in offshore waters around the world, during the last 25 years, only one--the infamous Mexican blowout in 1979-- produced an oil spill.

Directed by rigorous government drilling regulations and regular inspections, Dome has spared no effort in developing environmentally safe systems since it began operations in the Beaufort Sea. The purpose of these systems is to prevent a major oil spill from occurring. However, despite the implementation of all the possible fail-safe systems it is still possible for a blowout to occur. Therefore, it is obviously prudent to be prepared to respond should this happen.

The essential components of a successful response to an oil well blowout would include:

1) appropriate contingency plans
2) sufficient logistical support
3) comprehensive training programs
4) technological capabilities

A contingency plan has been developed that brings together, in times of an emergency, all available resources from across Canada. All of Dome's resources would be supplemented by other industry resources, through existing cooperative arrangements, and government support through such agencies as the Canadian Coast Guard.

The experience and knowledge gained from six years of drilling in the Beaufort Sea has led to improvements in both the drilling program and the technology for oil spill clean-up. Field training programs and classroom simulation exercises are carried out regularly, just like fire-drills, to satisfy stringent government operating conditions and to provide each employee with decision-making experience in his particular area of responsibility. All of this has resulted in an enhanced capability to maintain the safety of the fragile Arctic environment.

Although the work done to date is considerable, there is always room for improvement; so, an extensive research and countermeasures program is conducted every year to develop new technologies and to upgrade the existing oil spill clean-up capabilities.

The purpose of the following pages is to describe these existing and future capabilities. First, let us briefly look at the problem itself: an oil blowout in the Southern Beaufort Sea.

BLOWOUT BEHAVIOUR IN THE BEAUFORT

Currently, Dome's Beaufort drilling operations take place during the 3-4 month period of summer when the area is mostly ice-free. If an oil and gas blowout were to occur during this period, it would look very similar to the Mexican Ixtoc I blowout that took place in the Gulf of Mexico in 1979. Oil would rise to the water's surface, partially burn in the fireball formed by the burning gas, and ultimately be swept from the area by currents and winds.

In summer, the Beaufort Sea is relatively calm. Compared to the more frequent year-round turbulence in the North Sea or Gulf of Mexico, the Beaufort has moderate waves (less than 1.5 metres most of the time) and gentle sea currents (generally under 1.4 kilometres per hour). Both these factors greatly assist oil spill clean-up.

However, for most of the year the Beaufort is frozen and the ice cover is virtually continuous. In winter, fractured ice thrusts both upwards and downwards under the forces exerted by colliding floes. Much of the ice is in constant motion, drifting with wind and currents, primarily in a westerly direction. This ice is influenced by the polar pack, a vast collection of thick ice floes, which move slowly and relentlessly in a clockwise circulation pattern north of the drilling zone.

If a blowout that occurred in summer did not seal itself or was not controlled by a relief well before the onset of winter, the well could run unchecked until the following spring. During the winter, the rising oil from the blowout would "paint" the underside of the moving ice sheets. If one assumes that winter lasts for 200 days and the average western movement of ice is 2.5 kilometres per day, then the result would be a painted strip of oil 500 kilometres long, approximately 160 metres wide, containing a few hundred thousand metric tonnes of oil.

This prospect is not as frightening as it might at first seem. After many years of research by both government and industry, it has been determined that ice is nice insofar as oil spill control is concerned. Ice provides a natural containment barrier for the oil and prevents it from spreading to vulnerable shorelines. Because ice grows downward, oil that spreads under the ice becomes sandwiched between the layers of ice and depending on the time of year, is encapsulated very quickly--in as little as 12 hours.

Oil which is trapped and preserved in ice all winter stays fresh and is therefore easy to burn off. About a month before spring breakup, the oil rises to the surface through two processes. Oil deposited under thin ice, early in winter, is exposed through ablation (when ice melts down to the oil). Oil deposited under thicker ice, later in winter, is mostly exposed through migration--a process whereby oil seeps upward through small holes in the ice made by salt concentrations. Once on the ice surface, the oil collects in pools thick enough to burn. Field tests have shown much of the oil can be burned directly on the ice, using air deployable igniters. More on this later.

SUMMER OPEN WATER CLEAN-UP

The main priority of the oil spill contingency plan, for the Beaufort Sea, is to protect the areas which Northerners use and where birds, fish, whales and other important wildlife can be found. To this end, there is in place a three-tiered system for handling an oil well blowout, if one were to occur during exploratory drilling in the summer open water months.

The first line of defense is to burn the oil on the water surface above the blowout. Water currents from the rising gas bubbles create a natural containment ring for the oil, which tends to concentrate within the wave-ring around the blowout plume. (Slide 1).

For oil that is not contained and burned within the wave-ring, the second line of defense would be put into action. This consists of a boom to contain the oil, a skimmer to recover it and a burning system to dispose of it. The entire system of equipment is mounted on the

Response Barge which is stationed at Tuk base. If a major spill did occur at a drillship, the barge could be at the spill site in less than 24 hours and the entire system could be deployed and operational in less than an hour. Given the generally calm conditions of the Beaufort, the boom, skimmer and burner would be effective at least 90% of the time.

The Arctic boom is specially designed for offshore use in the Beaufort Sea. With solid flotation and a deep underwater skirt, this 1.5 metre high boom will contain oil in a stormy sea. Made of reinforced conveyer belting material, the boom can even withstand some contact with floating ice chunks.

When the boom is deployed in a V-configuration it can funnel the contained oil to the forward end of the barge. (Slide 2) To remove the floating oil, a Lockheed Skimmer with rotary blades and wipers has been used. This skimmer has been modified by the addition of a new ice processing pump, an enlarged oil recovery area and other changes for Arctic conditions. At the present time, a new concept Arctic Skimmer with more efficient pick up capability in partially ice-covered waters, at sub-zero temperatures, is being investigated. When proven, it will be added to the equipment arsenal for the Beaufort.

To dispose of the recovered oil, a burner is mounted on the Response Barge. The recovered oil can be burned off at a rate of up to 800 cubic metres per day. (Slide 3)

The third line of defense, chemical dispersants, would be used as a last resort only if wildlife and other resources are in jeopardy. These chemicals, like dishwater detergents, break down the oil slicks into small oil droplets which then disperse into the water. However, as the relative effectiveness of dispersants in cold water is still under investigation, Dome does not at this time rely heavily on their use as a countermeasure for an Arctic oil spill.

Through these three lines of defense, every effort possible is made to prevent an oil slick from reaching the shoreline. However, should an oil slick threaten Arctic shores, then the contingency plan for shoreline protection and clean-up would be initiated.

The plan of action for dealing with oil near the shoreline involves a four-step process. First, the probable path of the oil slick is predicted, so it can be dealt with before it reaches the shoreline. Second, critical areas are quickly identified for immediate protection. Third, prevention and clean-up equipment are deployed to protect the shoreline, while skimmers and burners are used to recover and dispose of the oil. Finally, birds and other animals are kept away from the area with various types of deterrent devices.

TRACKING THE OIL

If an oil spill were to occur on the open sea, it would be immediately detected and tracked, it would be observed from ships and aircraft, while radio-tracked buoys would be deployed to trace the slick's movement and relay the pattern by telex or computer.

A computer tracking program has been developed for the Beaufort Sea which can predict the movement and fate of an oil slick. The computer converts weather forecasts into a map of the slick's movement over the next 48-hour period. Using recorded weather and wind data, the computer generates an inventory of possible drift patterns. The model determines which shoreline areas might be hit, how long it will take before contact and how much oil can be expected to be washed ashore.

IDENTIFYING SHORELINE AREAS AT RISK

Once the oil is tracked, the on-scene commander would turn to the Beaufort Sea Atlas and the Shoreline Protection and Clean-up Manual. These provide all the necessary information for quick and well-informed decisions in an emergency.

When Dome began drilling in the Beaufort in 1976, it initiated a study of sensitive areas requiring protection from an oil spill. An atlas of the coastal area was prepared from extensive research, interviews and shoreline reconnaissance. Aerial photographs were taken of the entire shoreline from the Alaskan border to Baillie Island. The resulting Beaufort Sea Atlas was produced. It contains hydrographic charts with overlays of key areas and photographs of representative regions.

To update and verify the information in the Atlas, an intensive field program over two years was conducted along the Beaufort coastline. From this fieldwork, the Atlas was expanded into a concise easy-to-use Shoreline Protection and Cleanup Manual for the Southern Beaufort Sea.

In this Manual, the coastal area along the 2,240 kilometres of shoreline was ranked according to its human, biological and geological sensitivity. This ranking allows the on-scene commander to quickly direct his attention to threatened areas with the highest ranking. For each location, the Manual also outlines clean-up strategies appropriate to each specific shoreline area. As a supplement to the Manual, the entire Beaufort Sea coastline has been videotaped to provide a library of additional information for the on-scene commander.

PROTECTING THE SHORELINE

At Tuk, of the 10,000 metres of boom available, there are over 6,000 metres of shoreline boom. This boom would be placed across important bays, spits and lagoons to prevent the oil from reaching the shore. Compared to the heavier offshore boom which must withstand high waves, the near-shore boom is compact and lightweight. It can be quickly transported and rapidly deployed at the scene of the spill.

In shallow bay exercises, various lengths of near-shore boom (up to 730 metres) have been placed from one end of the bay to the other in less than 15 minutes. The contained oil is then skimmed and flared off with a portable burner. (Slides 4 and 5)

A Rotary Cup Burner, which can be carried to an oil spill site by helicopter, has been developed and tested. The burner will handle water-in-oil emulsions that are as much as 60% water by volume. It can flare off 80 cubic metres of oil a day, depending on the amount of water in the emulsion. This means that an oil slick 8 hectares in area and one millimetre thick can be completely disposed of in 24 hours. (Slides 6 and 7)

The burner was developed over a three-year period. The behavior of Arctic oil emulsions was studied in the laboratory to determine the basic requirements for the burner. As a result of these studies, a burner was designed and tested. After modifications, the burner was shipped North for field tests at Tuk. Over a five-month period, in the summer of 1981, the portable burner was successfully field tested. During this period of time it was used to dispose of approximately 3,600 cubic metres of waste oil that had been accumulated over the previous five seasons of Northern operations.

The portable burner is now a successful piece of oil disposal equipment for oil spill countermeasures in the Arctic.

PROTECTING BIRDS AND WILDLIFE

While the oil is being contained by near-shore booms, various deterrent devices would be used to keep waterfowl and other animals from landing on a spill site. Field work has been done with deterrents like bird-scare cannons, electronic bird alarms and helicopters. Even ultra-sonic methods have been investigated. Vision-based deterrents such as dyes for colouring the spilled oil and coloured objects have also been evaluated.

The results of these studies and tests so far indicate, surprisingly, that helicopters and human activity are probably the most effective bird deterrents available. Bird-scare cannons were also found to work well over short periods of time.

NEW DEVELOPMENTS

FIREPROOF BOOM

New approaches to Arctic oil spill recovery are continuing to be investigated. One result has been the development of a fireproof boom. (Slide 8) This boom contains and concentrates oil so that it is thick enough to burn while still on the water's surface. It can sustain flames and intense heat and has been designed to contain oil in waves equivalent to some of the roughest sea states in the Beaufort Sea.

Over one-half million dollars has been spent in the past three years to design and test this stainless steel boom. The first attempt at a fireproof boom, the "quickie" boom, was built with six oil drums and a heat resistant connector. After this, a more durable boom was constructed of stainless steel floats connected by a non-flammable accordion-pleated section.

The boom was first tested in waters off British Columbia for its ability to stay in tow and withstand the heat of burning oil. It was then taken to a test tank of the U.S. Environmental Protection Agency in New Jersey. Here, the boom was tested for its ability to contain, thicken and burn oil in simulated waves and currents. In the tank, the boom proved it could contain and burn oil in waves equivalent to 1 to 1.5 metres and winds of approximately 35 kilometres per hour--typical Beaufort offshore storm conditions. (Slides 9 and 10)

The final step in this development program will require that the boom undergo a rigorous field testing program in the offshore waters of Canada. Only after successful completion of these offshore trials will the fireproof boom be added to the stockpile of oil spill equipment in the Beaufort Sea.

SUB-SEA CONTAINMENT

Another concept that is being investigated involves the use of a sub-sea containment technique. This concept could be used not only during the open water's season but also throughout the winter in the Beaufort. Oil and gas released from a sub-sea blowout would be funneled through large, flexible hoses to a floating containment ring at the water's surface. (Slide 11) The oil and gas would then be burned off within the ring. Preliminary work on this concept is well under way and field trials will soon be undertaken.

RECIPROCATING KILN

A portable kiln is being modified to remove spilled oil from beach sand. The design is based on a rotary kiln which was used successfully in a Nova Scotia spill involving the tanker Kurdistan. Oil soaked sand is shovelled into one end of the kiln. The sand is heated and tumbled to burn off the oil, leaving clean sand that can be replaced on the beach. Blueprints for the three-piece portable kiln have been prepared and the kiln is ready to be constructed and tested for Arctic conditions.

PORTABLE DEBRIS INCINERATOR

To complement the reciprocating kiln, research is being carried out on an air transportable incinerator which will be able to dispose of oil-contaminated debris at the rate of approximately 1 tonne per hour. It is anticipated that this incinerator will be ready for field testing in the Beaufort, during the summer of 1982.

DISPERSANTS

Investigations are continuing on the use of dispersants for shoreline clean-up. Much of the work is being done cooperatively through the BIOS (Baffin Island Oil Spill) Project. This is a $6 million government and industry program which is studying, in part, the effects of using dispersants under Arctic conditions. Through this project, the impact of treated and untreated oil on the near-shore environment and the use of dispersants for shoreline protection and clean-up will be more clearly known.

FALL FREEZE-UP AND WINTER ICE

If an oil well blowout in the Beaufort Sea were to occur during freeze-up in the fall and continue through the winter months, the main clean-up would take place during the spring.

During the winter months, the oil deposited under the moving ice would be tracked by placing market buoys periodically on the ice, near the blowout site. These buoys would relay their position by satellite, on a daily basis, enabling the oil to be tracked by following the ice movement.

Any oil spotted on the ice surface or in open water leads would be ignited and burned in situ. A research study has been recently completed which demonstrated that crude oil can be ignited and burned in ice cracks at temperatures down to -35° Celcius and in wind speeds in excess of 35 kilometres per hour.

Important research is being conducted on various systems for the mechanical recovery of oil under and within ice during winter and freeze-up conditions. One such system, the sub-sea containment technique, was previously discussed under new developments for the open water situation. Another system being considered is an under-ice oil vacuum cleaner. Other concepts being investigated would make use of the ice-breaker, the Kigoriak, as well as the dredges stationed in the Beaufort Sea.

SPRING BREAKUP - IN SITU BURNING

The main clean-up of unburned oil from a well blowout at the end of the drilling season would take place in the spring. As already mentioned, in a blowout, oil is released to the surface, until a relief well is drilled or well seals itself. However, if the flow does not stop during the same season, the oil remains encapsulated in the ice throughout the winter. In the springtime, the oil rises to the surface, collects in pools, and can then be disposed of through in situ burning.

OBSERVING OIL AND GAS UNDER ICE

Industry has recently completed a major study that investigated the fate and behaviour of oil, released in the presence of gas, from a sub-sea blowout under first-year ice.

An experimental spill in 1975 in the Northwest Territories showed that oil, without gas, is easily burned off when it rises to the ice surface in the spring. Later laboratory work studied the effects of gas on the spread of oil under ice.

The most recent project was undertaken to test in the field how easily oil, with gas, that rises to the ice surface can be ignited. The project also investigated the optimum time to use igniters and what type of igniters worked the best.

The results of the field trials proved highly encouraging for reducing the effects of a sub-sea blowout. The oil rose to the ice surface in the spring and accumulated in pools thick enough to burn. Some 80% of the discharged oil was totally removed from the marine environment. The remaining 20% dispersed naturally into the offshore waters.

The experiment took place in three phases over eight months, from December 1979 through July 1980. In the first phase, approximately 6 cubic metres of oil with gas were discharged under the ice. During the second phase (5 months later), two more discharges took place comparing the effects of the time of discharge an oil rising to the surface. In the final phase, the appearance of oil on the surface was monitored and recorded.

Daily readings of oil temperature, volume, area and thickness were taken. Oil samples were collected for analysis. The pools were studied with radar surveys and regular aerial photographs. A film recorded the test burning by igniters.

The experiment revealed a number of significant facts. Most of the oil formed large droplets which clung to the under surface of the ice within a 50-metre radius of the blowout plume. Dring spring, 85% of the oil appeared on the surface, either by the ice melting or the oil migrating through brine channels (Slide 12) before the ice sheet completely rotted. Because the oil did not weather while encapsulated in the winter ice, it was easily burned off using igniters deployed from a helicopter.

AIR DEPLOYABLE IGNITERS

Large scale burning over a wide area with many thousands of oil pools, requires igniters which can be dropped from helicopters.

Igniters are a versatile countermeasure which can be used year-round for different types of applications in spring, they will ignite oil collected in pools on the ice surface. In fall or winter, they will ignite oil between or on ice floes. In summer, they can ignite oil contained on the open seas within a fireproof boom.

The first step in developing a suitable igniter was to select the most efficient ignition fuels. The chemicals chosen were "solid propellant" (or rocket fuel) to preheat the oil, and gelled kerosene (solid barbecue lighter) to burn 5 to 10 minutes until the oil slick became self fuelling.

The initial design of the air deployable igniter consisted of the two different types of fuel sandwiched between steel grids and fired by a standard safety fuse. A block of wood on either side provided strength and buoyancy.

In the spring of 1978, the original air deployable igniter was tested in the Northwest Territories. Igniters were dropped from a stationary helicopter into pools of oil on ice. They successfully burned 95% of the oil. Further tests helped to develop the igniter to its present state where it is more durable, compact and efficient. (Slide 13).

The redesigned igniter was tested in simulated field experiments in Ontario and given a final field test near Tuk base. When deployed from a helicopter flying at 5 kilometres an hour and at a 5-metre altitude, the igniters proved to be extremely effective in igniting oil in melt pools. Since then, minor modifications have been made to extend the storage life of the igniters.

CONCLUSION

It is not intended to leave the impression that oil spill clean-up in the Beaufort Sea is easy or that there would be no environmental damage in the event of a major spill. Rather, the purpose is to demonstrate that during the past six years of operation in the Beaufort Sea much has been learned about the Arctic and that this knowledge has been incorporated in the oil spill countermeasures program. This has resulted in an enhanced oil spill clean-up capability in the Arctic.

Today in the Beaufort Sea, contingency plans are in place; extensive and complete logistical backup is available in the form of boats, planes, oil spill equipment and personnel; comprehensive training and exercise programs have been carried out; and technology is rapidly evolving--all these resources would significantly reduce the impact of an Arctic oil spill. Many of these plans, logistic capabilities, programs and techniques were not available and much of the technology was not even conceived when exploration first began offshore in the Beaufort Sea.

The concerns expressed by private individuals and organizations are being listened to. Much work has been done and more is being undertaken. Industry as a whole and on an individual basis is responding to the challenge of Arctic oil spills.

EPILOGUE

In order to produce and transport crude oil from the Beaufort Sea, continued innovation in Arctic technology is required. The planning, engineering and testing of such systems, based on the successes of the last six years, is underway.

As with exploratory drilling, the primary environmental concern associated with production and transportation operations is a major oil spill. Through research and development, industry and government will continue to ensure that the systems for use in the Beaufort Sea are as spill-free as possible. Adapting proven oil spill countermeasures and developing new ones as required will ensure that one of the world's most successful oil spill countermeasures program continues.

OIL SPILL RESPONSE IN THE ARCTIC

PART 2

FIELD DEMONSTRATIONS IN BROKEN ICE

August, 1983

Administered and Conducted by

SHELL OIL COMPANY
SOHIO ALASKA PETROLEUM COMPANY
EXXON COMPANY, U.S.A.
AMOCO PRODUCTION COMPANY

With Additional Support From

ARCO ALASKA, INC.
CHEVRON U.S.A., INC.
MOBIL OIL CORPORATION
PHILLIPS PETROLEUM COMPANY
TEXACO, INC.
Anchorage, Alaska

ABSTRACT

During June and July, 1983, members of the oil industry in Alaska conducted field demonstrations of the state-of-the-art techniques for dealing with oil spills during periods of broken ice in the Beaufort Sea. The six demonstrations were observed by Federal, State of Alaska, and North Slope Borough representatives. This field program was required by the State as a necessary part of the industry's efforts to obtain approval for year-round exploratory drilling.

In April, 1983, the industry prepared a draft report which provided the basic state-of-the-art information from which the six demonstration areas were identified. That report which is entitled Oil Spill Response in the Arctic, An Assessment of Containment, Recovery, and Disposal Techniques, is Part 1 of the industry's assessment of spill response in the Arctic. The results of the six demonstrations are being provided here as Oil Spill Response in the Arctic, Part 2, Field Demonstrations in Broken Ice.

ACKNOWLEDGEMENTS

This report is the result of the efforts of the industry Task Group and its consultants, as well as the on-scene contractors who helped stage and carry out the six demonstrations described in this report.

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1.0 ABSTRACT

Exploratory drilling for oil and gas in the Alaskan Beaufort Sea has been restricted by regulatory agencies because of their concerns about the technology and the oil industry's ability to clean up oil spills in broken-ice conditions. During late 1982 and early 1983, oil companies worked closely with representatives of the State of Alaska, the Federal Government, and the North Slope Borough to evaluate this technology and to design demonstrations of specific response capabilities. These demonstrations were carried out in June and July, 1983, in an onshore pit near Prudhoe Bay, Alaska, and in ice-infested waters of the Beaufort Sea.

The first demonstration, Task 1, involved the in-situ burning of crude oil in the presence of scattered broken-ice pieces. Task 2 involved the burning of oil inside a fire containment boom. In both tasks, numerous tests were conducted with varying environmental conditions and amounts of oil, and burn efficiencies of from 55% to 95% were obtained. During Task 3, a self-propelled rope-mop skimmer (ARCAT II) was tested and evaluated in up to 7 oktas ice coverage.

Task 4 focussed on the logistical support capabilities of tugs and barges in heavy ice concentrations during breakup. During Task 4, a 200-foot ice-breaking barge was used in conjunction with a mile-long train of tugs and barges over a route in excess of 100 nautical miles with up to 8 oktas of decaying ice. In Task 5, a conventional barge was used to demonstrate the feasibility of operating rope mop skimmers from conventional barges in moving broken ice. Varying sizes and configurations of rope mop skimmers were operated in up to 7 oktas of ice coverage. During Task 6, more than 500 feet of fire containment boom were deployed in moving broken ice in the lee of a drilling island. The feasibility of lifting such boom with a helicopter and deploying it among moving broken ice was also demonstrated.

2.0 BACKGROUND

In 1978, the State of Alaska and the U.S. Department of the Interior imposed seasonal drilling restrictions on all leases to be awarded in the 1979 State/Federal Beaufort Sea Lease Sale. Agencies had imposed restrictions limiting exploratory drilling to the five-month period from November 1 to March 31 of each year. The rationale utilized for the imposition of the restriction was related to bowhead whale migrations and the oil industry's ability to clean up oil spills.

Subsequently, the industry participated in numerous public workshops, meetings and hearings which dealt with the issues related to the seasonal drilling restrictions. Additionally, in 1981 and 1982, members of the industry distributed to State and Federal agencies an extensive technical report analyzing all the issues related to seasonal drilling. In May, 1982, the State of Alaska, with agreement from the Federal Government, revised the seasonal drilling restrictions to include a two-tier system. Tier 1 regulations restrict drilling during: 1) periods of broken ice, 2) periods of open water for locations outside the barrier islands, and 3) the fall bowhead whale migration for locations outside the barrier islands. Tier 2 regulations allow unrestricted drilling, with the exception of locations outside the barrier islands during the fall bowhead whale migration. This level applies only to "lessees who demonstrate compliance with applicable laws and regulations, including the theoretical and physical capability to detect, contain, clean up and dispose of spilled oil in broken ice conditions."

During November, 1982, industry representatives met with the Commissioners of the Alaska Department of Natural Resources (DNR) and Alaska Department of Environmental Conservation (DEC) to discuss procedures for implementing the Tier 2 level of seasonal drilling restrictions. DNR proposed that interested oil companies conduct an oil spill response demonstration to determine if the industry could satisfy Tier 2 requirements. As conceptualized by DNR, this demonstration would be performed and evaluated in accordance with criteria developed by the State.

In February, 1983, a joint agency/industry Steering Committee was formed to insure that the Tier 2 demonstrations would address the concerns of interested parties as well as assess existing technology. This committee was responsible for making sure that the planning effort for the Tier 2 demonstrations was completed in a timely manner. The Steering Committee included the Commissioners of DNR and DEC; the Commander of the 17th U.S. Coast Guard District; The Regional Manager of the Alaska OCS Region, Minerals Management Service; the Mayor of the North Slope Borough; and management representatives from Shell Oil Company, Sohio Alaska Petroleum Company, Exxon Company, U.S.A., and Amoco Production Company.

A Technical Committee consisting of personnel from the organizations represented on the Steering Committee was also established. The Technical Committee was responsible for the evaluation of the oil spill response technology and the development of appropriate demonstrations.

During the technology review process carried out by the Technical Committee, an oil industry Task Group was formed consisting of representatives from the Technical Committee and their consultants. Shell coordinated this effort with assistance from Sohio, Exxon, and Amoco. The objectives of the Task Group were to conduct an in-depth state-of-the-art assessment of existing oil spill response capabilities for the Arctic and prepare a report emphasizing those techniques that are most applicable to the broken-ice period.

2.1 State of the Art Assessment

The industry Task Group prepared a draft report, Oil Spill Response in the Arctic, An Assessment of Containment, Recovery and Disposal Techniques, to provide a summary of the industry's assessment of the state-of-the-art containment, recovery, disposal, and logistical support capabilities for a major oil spill in the Alaskan Beaufort Sea. Specific spill response procedures were assessed with respect to applicability, effectiveness and sensitivity to environmental extremes.

The report contains a summary of those techniques and logistical support systems considered to be the principal response procedures and modes of response for the Arctic. The report reveals that in-situ burning is the primary response technique for a major oil spill in the Arctic. Burning in place can often provide an effective means of eliminating spilled oil, thereby minimizing the potential for oil impact to offshore and onshore natural resources.

In-situ burning would be enhanced during the winter, early spring, and fall freeze-up due to the natural containment (or barrier effects) provided by ice. During periods of low ice concentration and during open-water conditions, containment would include the use of man-made fire containment barriers. Such fire-resistant, floating booms would help limit the spread of oil and concentrate the oil to enhance the efficiency of combustion. In-situ burning techniques during breakup are generally quite feasible for the following reasons:

- Cold air and water temperatures result in oil equilibrium thicknesses on the order of 0.1 inch or greater (well above the minimum thickness required for combustion).

- Relatively calm wind and sea conditions prevail during a majority of the breakup period.

- Floating ice in heavy concentrations will help confine oil slicks and dampen wave action.

- Concentrated oil slicks can be ignited using helicopter-deployed igniters (avoiding undue risk to personnel and vessels).

The report provides additional information on various mechanical recovery techniques that are applicable throughout the year. Rope mop skimmers, manual removal, and the Alaskan Beaufort Sea Oilspill Response Body's (ABSORB's) ARCAT II skimmer are shown to represent significant cleanup techniques over a broad range of ice conditions. Many specific oil spill response techniques are addressed in detail in the report.

In addition, the report contains an assessment of those environmental conditions (i.e., temperature, visibility, moving broken ice, and winds) that could influence arctic cleanup operations. The magnitude, period, and/or frequency of such conditions are presented for the year, with emphasis provided on those environmental factors most likely to influence a spill response during broken-ice conditions.

2.2 Field Demonstrations

The agencies reviewed the industry's state-of-the-art report and identified their areas of agreement and disagreement. The Tier 2 Technical Committee then developed six demonstration tasks which would involve a modular approach and address oil spill response techniques and equipment of concern. The time frame for the demonstrations was set for the 1983 breakup season.

The six preliminary task descriptions and the industry's draft state-of-the-art report were distributed to appropriate Federal, State and local agencies as well as the oil industry and the public. The State's description of the seasonal drilling restrictions and the State's analysis of the industry's state-of-the-art report were also distributed. Public meetings and a teleconference were held in May, 1983, permitting the public to participate in the review process. The State's consultants, S.L. Ross Environmental Research Limited, then presented its preliminary report, The Evaluation of Oil Spill Contermeasures in Broken Ice Conditions in the Alaska Beaufort Sea; Phase I: Design of Demonstration Tasks (Ottawa, Ontario, May 20, 1983). This report was used by the State during its review of the industry's broken-ice response capabilities.

After reviewing all pertinent information, the State accepted six tasks for demonstration. Summaries of these tasks are given below.

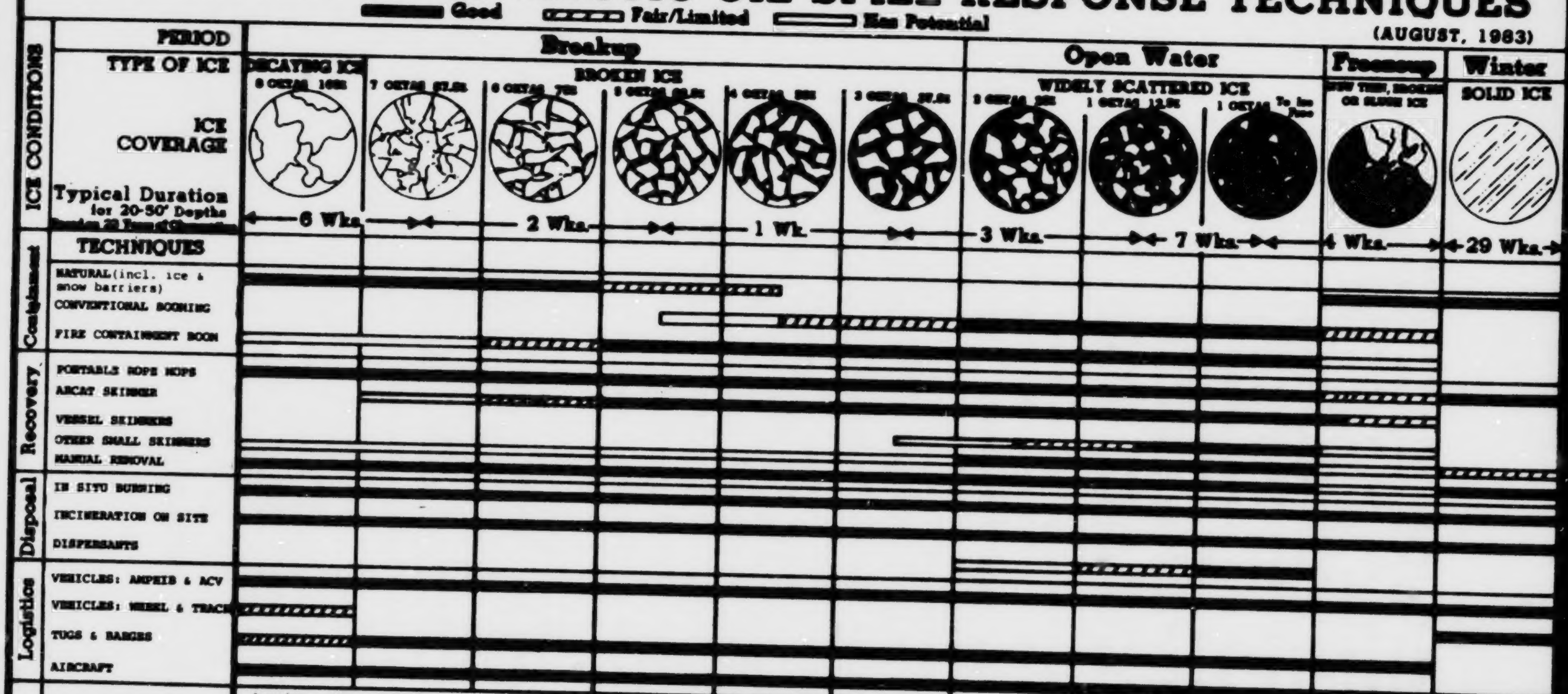
- Task 1

  Task 1 was to be accomplished in a suitable onshore pit to determine the effectiveness of igniters and the efficiency of in-situ burning of crude oil in scattered, broken ice ranging between 3 and 5 oktas (See Chart 1). Oil would be released in modes and volumes that are consistent with blowout scenario spill rates of 10,000 and 500 barrels of oil per day (bopd). The nature and efficiency of burning would be demonstrated after the oil in each release mode had spread to its equilibrium condition. It was felt that burning should take place without the aid of any artificial containment (i.e., booms or the sides of the pit). An assessment would then be made of the interaction of oil and ice before, during, and after each burn, as well as the efficiency of burn.

CHART 1

APPLICABILITY OF ARCTIC OIL SPILL RESPONSE TECHNIQUES

(AUGUST, 1983)



Response	Breakup (Decaying Ice)	Breakup (Broken Ice)	Open Water	Freezeup	Winter
PRIMARY RESPONSE TECHNIQUES & LOGISTICS	Burning with natural ice containment. Ignitors released from helicopters.	Burning with fire containment booming. Booms deployed with amphibious/air cushion vehicles, tugs & aircraft. Igniters released from surface & from helicopters.	Burning with fire containment booming. ARCAT skimmer with collection booming. Portable skimmers & manual removal from amphibious/air cushion vehicles, tugs, barges and small boats. Towable bladders & incineration.	In situ burning w/igniters. Use amphibious, ACVs & helicopters.	Manual removal, In situ burn, incineration. Use all vehicles and aircraft.
ADDITIONAL RESPONSE TECHNIQUES & LOGISTICS	Rope mop skimmers and manual removal from amphibious/air cushion vehicles and from tugs and barges. Storage & incineration on barges.	ARCAT skimmer. Rope mop skimmers and manual removal from amphibious/air cushion vehicles and tugs & barges. Storage & Incineration on barges.	Conventional sweep booming (avoiding ice). Backup self-propelled skimmers (avoiding ice). Dispersants (with low ice concentration and good mixing energy).	ARCAT Skimmer, small skimmers w/vessel's. Mark oiled area and waitfor solid ice	Slots & auger, use small skimmers direct suction. Wait to surface in spring

- Task 2

During Task 2, the ability of fire containment boom to contain burning crude oil would be demonstrated. The boom's ability to contain oil while surviving the extreme temperatures would be evaluated as a continuous supply of oil is fed to the contained fire. It was also determined that Task 2 should involve an assessment of the efficiency of the combustion process following each burn.

- Task 3

The objectives of Task 3 were to determine of the *ARCAT*'s ability to maneuver safely and effectively in broken ice and to operate its rope mop and weir recovery devices. The *ARCAT* would be operated during good visibility (for aerial observation and photograph) for one to two days with two simulated skimming periods of 4 hours each. Each skimming demonstration (without oil) would be followed by a transit to an offloading location to transfer the "recovered oil." It was felt that operations should be conducted in 2 to 4 oktas of coverage with moving broken ice and that this task should demonstrate the *ARCAT*'s stability, maneuverability and speed while skimming and during transit in the ice. The *ARCAT* would be tested for its ability to maintain a relatively fixed position while skimming in broken ice and for its potential in recovering simulated oil in close proximity to ice edges of slowly drifting floes. In addition, offloading procedures and equipment would be tested.

- Task 4

The purpose of Task 4 was to demonstrate logistical support capabilities for an oil spill response involving tugs and barges during broken-ice conditions. It was envisioned that the demonstration should be of sufficient duration in heavy, broken-ice conditions (5 to 6 oktas) to prove the utility of tugs and barges in moving personnel and equipment over large distances. This demonstration could be accomplished by observing and fully documenting actual industry support operations during breakup. Industry and agency representatives felt that such a demonstration could be achieved by observing the operation planned by Crowley Maritime Corporation to move two tugboats and the ice-breaking barge, the *Arctic Endeavor*, from Prudhoe Bay to Barter Island during breakup of 1983. The return trip over the same route of more than 100 nautical miles would involve

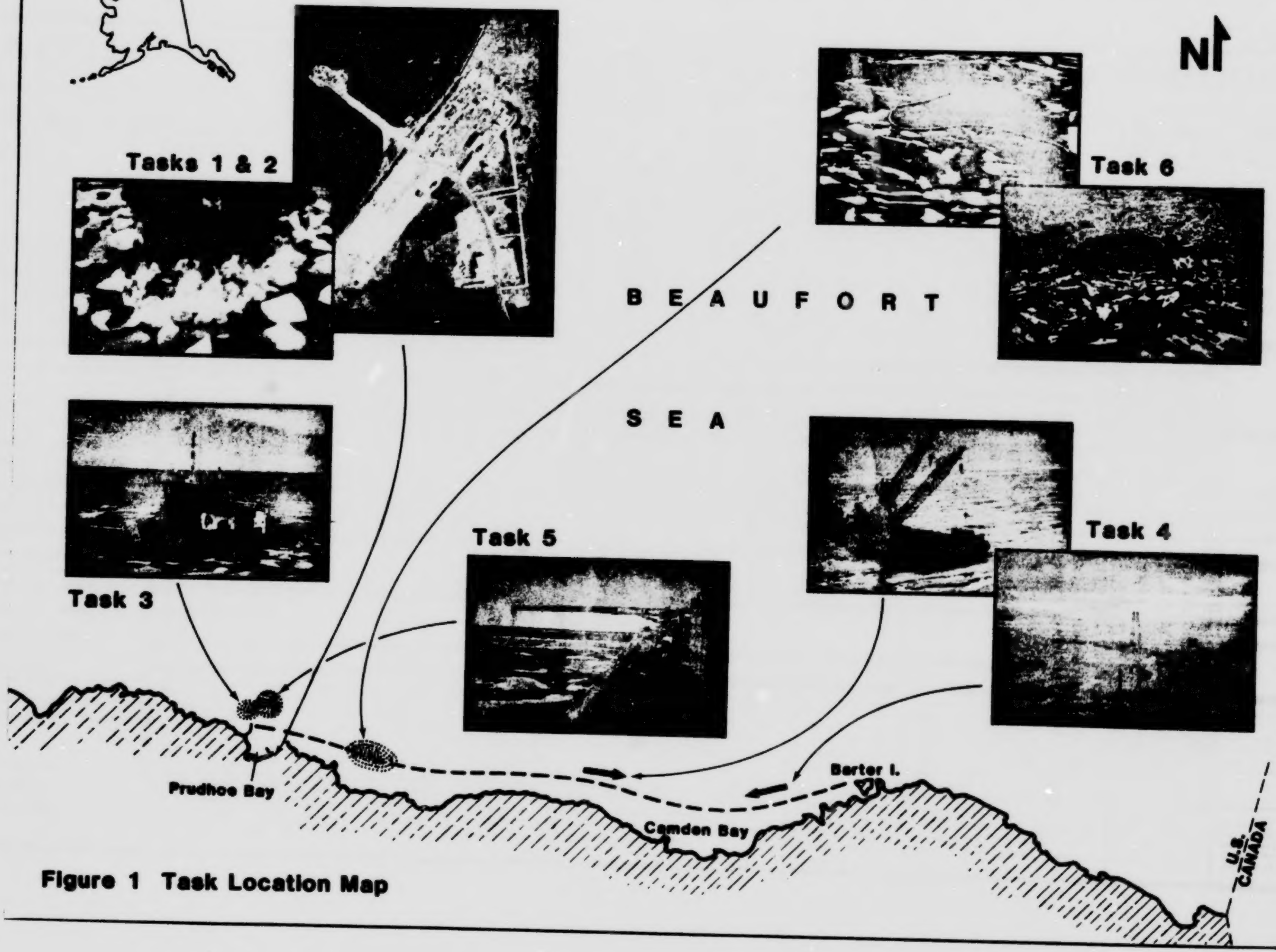

N
Tasks 1 & 2
Task 6
B E A U F O R T
S E A
Task 3
Task 5
Task 4
Prudhoe Bay
Camden Bay
Barter I.
U.S.
CANADA

Figure 1 Task Location Map

10 tugs and 15 barges travelling through varying degrees and conditions of moving, broken ice.

- Task 5

It was recommended that Task 5 be planned and implemented to assess the applicability of rope mop skimmers when operated from vessels (or barges) of opportunity in broken-ice conditions (2 to 4 oktas). The demonstration would involve the mobilization, deployment and operation of rope mops to evaluate their overall effectiveness in contacting areas of open water (between floes) near and adjacent to the support vessel. The skimming system would be tested over an 8-hour period with varying ice size and movement, with the evaluation criteria to include the need for repositioning the mop or vessel, the durability of the mop wringer assembly, any down time for repairs, effects of icing, etc.

- Task 6

Task 6 would focus on the logistical aspects of deploying fire containment boom in offshore, ice-infested waters. Approximately 500 feet of boom would be deployed in the lee of a drilling island with ice coverage of 4 to 6 oktas. It was felt that the boom should remain in the water for a minimum of one day in a simulated containment configuration. A suitable length of boom would also be deployed away from the drilling island in 3 to 5 oktas ice coverage and be allowed to drift with the moving ice floes for at least 24 hours. During the deployment and recovery of the booms, consideration would be given to safety, accessibility, and to the practicality of use in each mode. In addition, the survivability of the boom would be evaluated during all handling, transport and simulated containment phases.

3.0 SUMMARY OF RESULTS

During June and July, 1983, an industry field task group of personnel from Shell, Sohio and Exxon conducted and fully documented (videotapes, 16 mm movies, and 35 mm slides) the six demonstrations as defined by the State of Alaska. The field demonstrations are illustrated as Tasks 1 through 6 in Figure 1 along with their approximate areas of completion. The three companies coordinating the field program received financial support from Amoco, one of the original four sponsors, and from ARCO Alaska, Inc.; Chevron, U.S.A., Inc.; Mobil Oil Corporation; Phillips Petroleum Company; and Texaco, Inc.

3.1 Task 1: In-situ Burning of Oil in Scattered Ice

The in-situ burning of fresh Prudhoe Bay crude oil in Task 1 involved four separate tests in an onshore pit at Prudhoe Bay. Two of the tests were conducted with 36 gallons of oil each into 3 to 5 oktas ice coverage (grounded and floating), while the other two involved 288 gallons under the same conditions. The results of the four tests demonstrated that 1) cold waters and ice are beneficial in limiting the initial spread of oil, resulting in equilibrium thicknesses in excess of 0.1 inch; 2) such oil slicks are ignitable using existing techniques, including helicopter deployment of igniters; 3) the oil slicks can be burned, even in scattered ice conditions, with efficiencies of typically 55% to 85%; and 4) the unburned oil and burned oil residue can be recovered using conventional oil sorbent materials.

3.2 Task 2: Burning of Oil Inside Fire Containment Boom

During Task 2 the in-situ burning of crude oil was once again demonstrated in an onshore pit at Prudhoe Bay. In these tests, however, the oil was contained by Shell Oil Company's recently developed fire containment boom. One test involved the burning of a 1-inch layer of crude oil inside an 8-foot-diameter ring of fire containment boom over a period of 10 minutes. A second test included the same boom with a continuous supply of crude oil (at a rate of 2½ gallons per minute for 1 hour) to the ring during burning. The first two tests, conducted in mid-June, demonstrated that the fire containment boom would hold oil at least an inch thick without leakage and that the boom was capable of withstanding the heat generated by a single burn of crude oil 1 inch thick. The continuous burn involved a total containment of the burning oil for approximately 45 minutes (following the initial 10-minute burn). After that, the downwind side of the boom became submerged and burning oil escaped to a secondary fire containment boom. Burn efficiencies of 90% and 95% were experienced during the two tests.

Laboratory analyses of the test pit water and boom fabric following the partial sinking of boom in the pit test suggested that water quality may have caused the sinking. The boom was subsequently modified and additional tests were conducted during which contained crude oil was burned on fresh sea-water in a tank for 2 hours without boom failure. A section of burn-tested boom was saved for additional field deployment tests in Task 6.

3.3 Task 3: Operation of ARCAT in Broken Ice

Task 3 involved the field testing of ABSORB's 65 foot, ice-strengthened catamaran vessel, the ARCAT, under a broad range of ice conditions off West Dock, Prudhoe Bay. The vessel's capabilities were demonstrated as it transited 6 to 7 oktas of decayed ice coverage (6 to 36 inches thick) and as it maneuvered without difficulty in thicker broken ice pieces and along the edges of large ice floes. The test demonstrated the ability of the

ARCAT to transit ice concentrations of 3 to 5 oktas at speeds of 1 to 2½ knots and coverages of 2 oktas or less at 5 to 7 knots. When ice coverages exceeded 5 oktas, it was still possible to maneuver the ARCAT through the decayed ice at 1 knot or less.

The ARCAT's rope mop skimmers were operated in open water and in moderately heavy ice conditions (up to 7 oktas) for a period of about 8 hours. The durability and utility of the vessel's rope-mop oil recovery system, as well as its backup weir skimmer and dispersant spray system, were demonstrated. In addition, the ARCAT's recovered oil storage and internal heating units were placed in operation, and the vessel's fire monitors were used to demonstrate their potential in cleaning and flushing oil from ice surfaces.

3.4 Task 4: Operation of Barges and Tugs in Broken Ice

In Task 4, industry and agency personnel witnessed two major voyages of tugs and barges through extensive regions of dense pack ice. During mid-July, Arctic Marine Freighters and Kodiak Marine Transport were each engaged in the transport of oceangoing tugs and barges over considerable distances during breakup in the Beaufort Sea. Arctic Marine Freighters, a subsidiary of Crowley Maritime Corporation, used two 2,150-horsepower tugs to push its 200-foot ice-breaking barge, the Arctic Endeavor, through nearly continuous decaying ice fields between Prudhoe Bay and Barter Island. Completing the 100+-nautical-mile trip in just one day, the Endeavor averaged 4½ knots through regions 6 to 8 oktas in coverage over a majority of its route. Ice thicknesses were typically 3 to 4 feet, while many ice zones contained heavily rafted floes and grounded floebergs. On its return trip, the Arctic Endeavor was part of a fleet of 10 tugs and 15 barges which covered the same route, averaging 2.4 knots for the entire trip.

Kodiak Marine Transport's experiences with its 200-foot non-ice-breaking barge, the SATCO 10, also involved 2-knot speeds as their tugs and barge travelled the 55 nautical miles between Flaxman Island and Prudhoe Bay. As with the Crowley operation, Kodiak's progress in up to 8 okta coverage with thick, densely packed ice provided an excellent example of what can be accomplished using tugs and barges to satisfy massive logistical support requirements in the Arctic.

3.5 Task 5: Operation of Rope Mops from a Barge in Broken Ice and Open Water

Task 5 was completed aboard Kodiak Marine Transport's SATCO 10 barge with support from the tugboat Arctic Fox. Working in waters up to 5 miles off West Dock, the SATCO 10 was used as a support platform for the simulation of oil recovery operations in varying degrees and types of broken ice. The operation of the barge-and-tug combination demonstrated the feasibility of transporting personnel and heavy cleanup equipment through ice coverages of up to 8 oktas. The ability of the tug to maneuver a barge to achieve its most efficient orientation in accessing oil in or adjacent to an ice field was also demonstrated. Outfitted with all of the support systems that would normally be required to carry out such an oil recovery operation, the SATCO 10 operated with three rope mop skimmers in 2 to 7 oktas over an 8-hour period. While most of the demonstration took place in dense fog, the skimmers had a combined skimming time of nearly 17 hours, with only one minor shutdown to adjust the length of a rope mop. There were no mechanical breakdowns.

3.6 Task 6: Boom Deployment in Moving Broken Ice

Task 6 involved the deployment, maintenance and recovery of more than 500 feet of Shell's fire containment boom under actual conditions of moving broken ice (4 to 7 oktas) offshore near a drilling island. The boom, which contained a 30-foot section of boom used during the additional burn tests of Task 2, was positioned in a fixed containment mode in the lee of an offshore drilling island. With more than 24 hours of exposure, the boom was contacted at times by drifting ice cakes and floes moving past the island at up to 1/3 knot.

A second test included the air-lift, transport, and deployment of fire containment boom by helicopter in ice-infested waters remote from the island. A Bell 212 helicopter was used to move about 3,000 pounds of boom (i.e., 240 feet, wet) several miles from its pickup point and to set the boom in moving broken ice (up to 3 oktas). The deployment was conducted without difficulty, and the boom was recovered after it was allowed to drift freely for 2 days over 14 nautical miles.

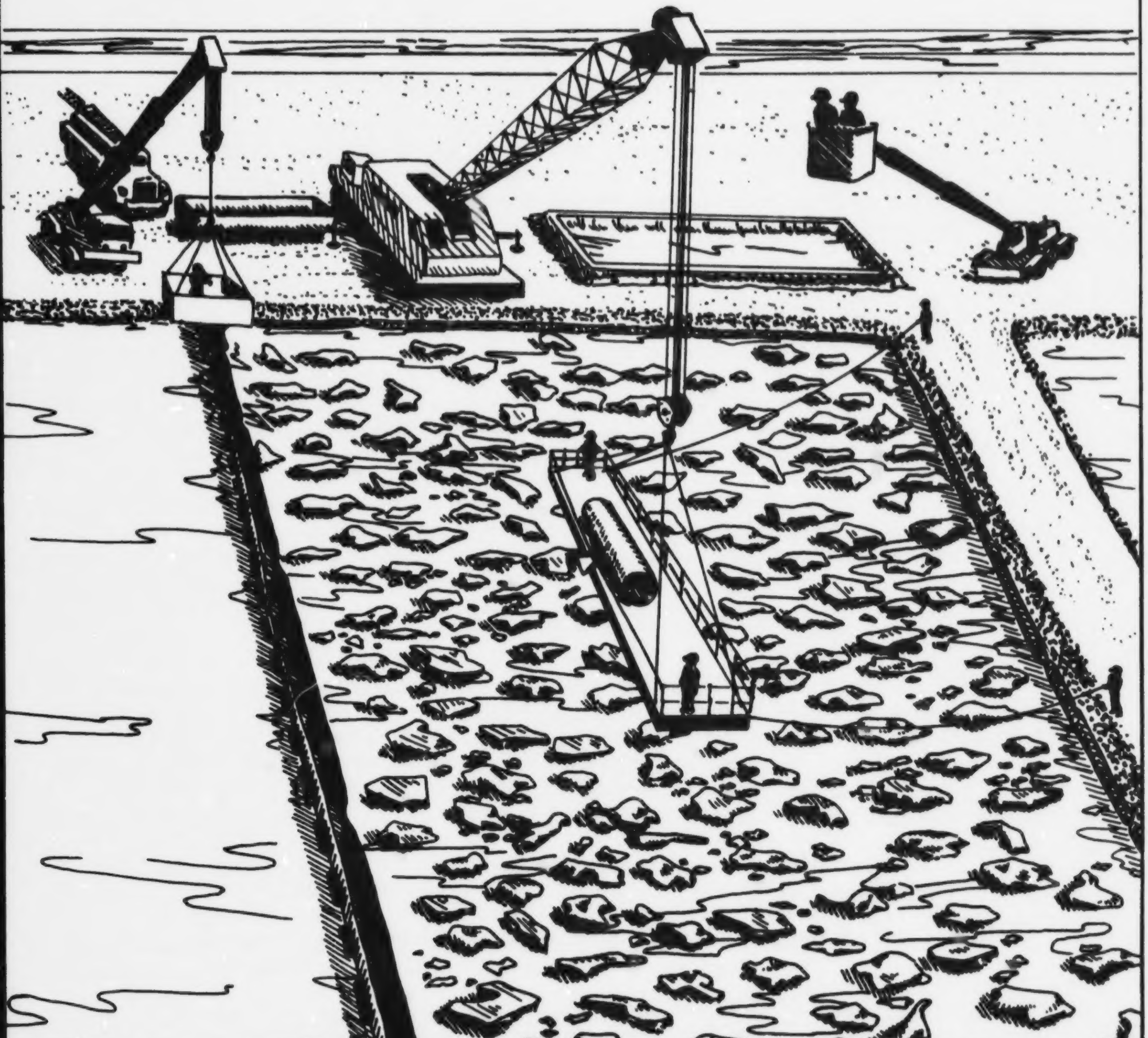
In both the island and free-drifting tests, the fire containment boom survived all handling and ice encounters without damage. The section exposed to an earlier burn test came through the demonstration without damage as well. Fire containment barriers such as Shell's boom tested in this task (and in Task 2) appear to offer an effective means of containing burning oil downstream of a fixed spill source. Such boom could also be used with helicopters or surface craft to contain oil and assist in its removal (through in-situ burning) even in a free drift mode with broken ice.

4.0 TASK DESCRIPTIONS

The six tasks described in general terms in Section A were conducted during June and July, 1983, both at onshore Prudhoe Bay facilities and at offshore locations in the Beaufort Sea. These demonstrations were conducted by the oil industry and observed by State, Federal, and North Slope Borough representatives. Before each demonstration was conducted, all necessary government permits were obtained, and appropriate safety meetings were held with field personnel.

TASK 1

In-Situ Burning of Oil in Scattered Ice (Tests 1 and 2)



Tasks 1 and 2 were carried out in an onshore pit at Sohio's Prudhoe Bay facilities near East Dock, while Tasks 3, 4, 5, and 6 were conducted in the Beaufort Sea. The tasks were not carried out in numerical order, but rather in the sequence that best accommodated the existing ice conditions.

The purpose of this section is to present detailed descriptions of the objectives, preparations, procedures, and results of the six demonstrations.

4.1 Task 1: In-situ Burning of Oil in Scattered Ice

The primary objective of Task 1 was to demonstrate the feasibility of in-situ burning of crude oil among scattered ice. Task 1 consisted of four individual tests which involved spills of 36 gallons and 288 gallons in both grounded and moving ice and which were conducted in an onshore pit at Prudhoe Bay.

The oil volumes and flow rates used in Task 1 were determined by State agency personnel to reflect the amounts of oil that would enter the Beaufort Sea from spills of 10,000 and 500 barrels of oil per day (bopd). The modes of release were selected to enable on-scene observers to examine the spreading and wind-generated transport of the oil through the ice pieces. Agency and industry representatives then evaluated the effectiveness of igniters and of in-situ burning (without artificial containment) in removing the oil.

As discussed in the following test descriptions (Tests 1 and 2), the objectives for in-situ burning initially involved the movement and the combustion of oil with 3 to 5 oktas (or approximately 50%) stationary ice. The ice was therefore deliberately grounded within the pit to prevent its movement and accumulation on the downwind side of the pit.

During Tests 3 and 4, however, the objectives were to evaluate oil and ice interactions, spreading phenomena, and combustion while oil and ice were free to move under the influence of wind. It was recognized that while the same oil discharge conditions (from Tests 1 and 2) were to be used in these latter tests, the oil and/or ice could possibly interact with the sides of the pit prior to or during the burning phase.

The objectives of the Task 1 were developed to answer specific questions such as:

- Will fresh, degassed Prudhoe Bay crude oil spilled under the conditions described spread to an equilibrium thickness that will support combustion?
- When the oil reaches its equilibrium thickness, will it be possible to ignite the oil?
- Should the oil slick be ignitable and support combustion, will the burning process involve the propagation of flame over a majority of the slick?

- Will the movement of oil through the ice during combustion result in the isolation of oil patches, thereby reducing the efficiency of in-situ burning?

- What kind of burning efficiencies can be achieved under the conditions tested?

- What are the nature and areal extent of burn residue following combustion, and can it be cleaned up effectively?

4.1.1 Test 1: 36-Gallon Spill into Grounded Ice

Preparations and Procedures

The Task 1 demonstrations were conducted in June, 1983, in a 150-foot by 210-foot section of an onshore pit located at Sohio's facilities at the Prudhoe Bay East Dock. Sea ice excavated 15 miles away at the West Dock was hauled to the pit for use in the demonstrations. Use of ice from the East Dock area was limited because it was more deteriorated and melted quickly when placed in the pit. Two front-end loaders, a backhoe and seven dump trucks were used to transport and place the ice pieces in the pit (Photo 1). An ice coverage of 3 to 5 oktas was established in the pit on June 10 (Photo 2), the day before the demonstrations began, while additional ice was stored alongside the pit for use if more was needed during the tests. Typically, the ice pieces were 2 to 4 feet thick and approximately 1 to 6 feet across. The pit contained water which had been transferred from a nearby drilling mud disposal pit. The water level was maintained so that the ice was grounded, with the top 1 to 2 feet of the ice above water.

A 250-foot length of Harbor Dike boom[1] was used to isolate the test area from the remainder of the pit and was protected by means of the Shell fire containment boom[2]. Further preparations of the pit included using sorbent boom to line the three gravel slopes that could contact oil. To provide location and distance markers, stakes were placed every 10 feet along two sides of the pit.

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[1] The Harbor Dike boom, which has a tensile strength of approximately 20,000 pounds, is a fence-type boom consisting of a ¼-inch nylon-reinforced PVC belting with foam floats and ballast chain attached.

[2] The fire containment boom used is one currently under development by Shell Oil Company and consists of a double layer of Thermoglass fabric over 3M-brand sorbent boom. Details are presented in the discussion of Task 2 in Section 4.2.

Major pieces of equipment included a 150-ton crane with a 120-foot boom. The crane was used to suspend a specially constructed 50-foot by 4-foot platform over the center of the pit for use by industry and agency observers and for holding the drum of oil to be discharged (Photo 3). Other major equipment included two camera platforms suspended from 35-ton and 20-ton hydraulic cranes; a fire truck; and Shell, Sohio, and ABSORB oil spill response vans. The general layout of the pit and the location of the major equipment are shown in Figure 2.

A "dry run" was conducted on the evening of June 20, 1983, to finalize test procedures, familiarize participants with their responsibilities, and provide an opportunity for agency personnel to review the procedures before the demonstrations. Prior to the dry run, a safety meeting was held with all personnel.

On June 11, 36 gallons of fresh, degassed Prudhoe Bay crude oil were discharged into the test pit from a 55-gallon drum supported on the crane-suspended platform. An initial 45-foot-long swath of oil was created in the pit by swinging the platform over the water for about 2½ minutes at a rate of approximately 0.3 feet per second. Oil was discharged at a rate of 15 gallons per minute through a 2-inch-diameter hose held approximately 2 to 4 feet above the water surface. Valve settings for oil discharge rates and platform velocities to establish the required oil slick length had been determined during the previous day's dry run.

After all the oil was in the pit, the slick was allowed to spread until the industry and agency representatives agreed that it had reached an equilibrium thickness. At that time, the oil was set on fire using floating igniters[3], which were dropped into the oil from the observation platform.

As the oil caught fire, video camera stopwatches were used to document the entire burn demonstration in real time. The burn was documented on half-inch VHS videotape, 16 mm movies, 35 mm slides, data sheets and as a running commentary on tape recorders.

After the fire had burned out, the oil residue was carefully recovered by eight men in chest waders using oil sorbent pads. The pads were counted and stored in plastic bags, and the water was allowed to drain out. The gross weight of the plastic bags, sorbent pads and recovered oil was then recorded. Since the weight of the bags and pads was known, the weight of the oil that was recovered could be determined.

In addition to removing and weighing all of the oil residue, samples of the unburned oil in the pit and the burn residue were taken for analysis by DEC. Samples of the water in the pit were also taken for chemical analysis by Sohio.

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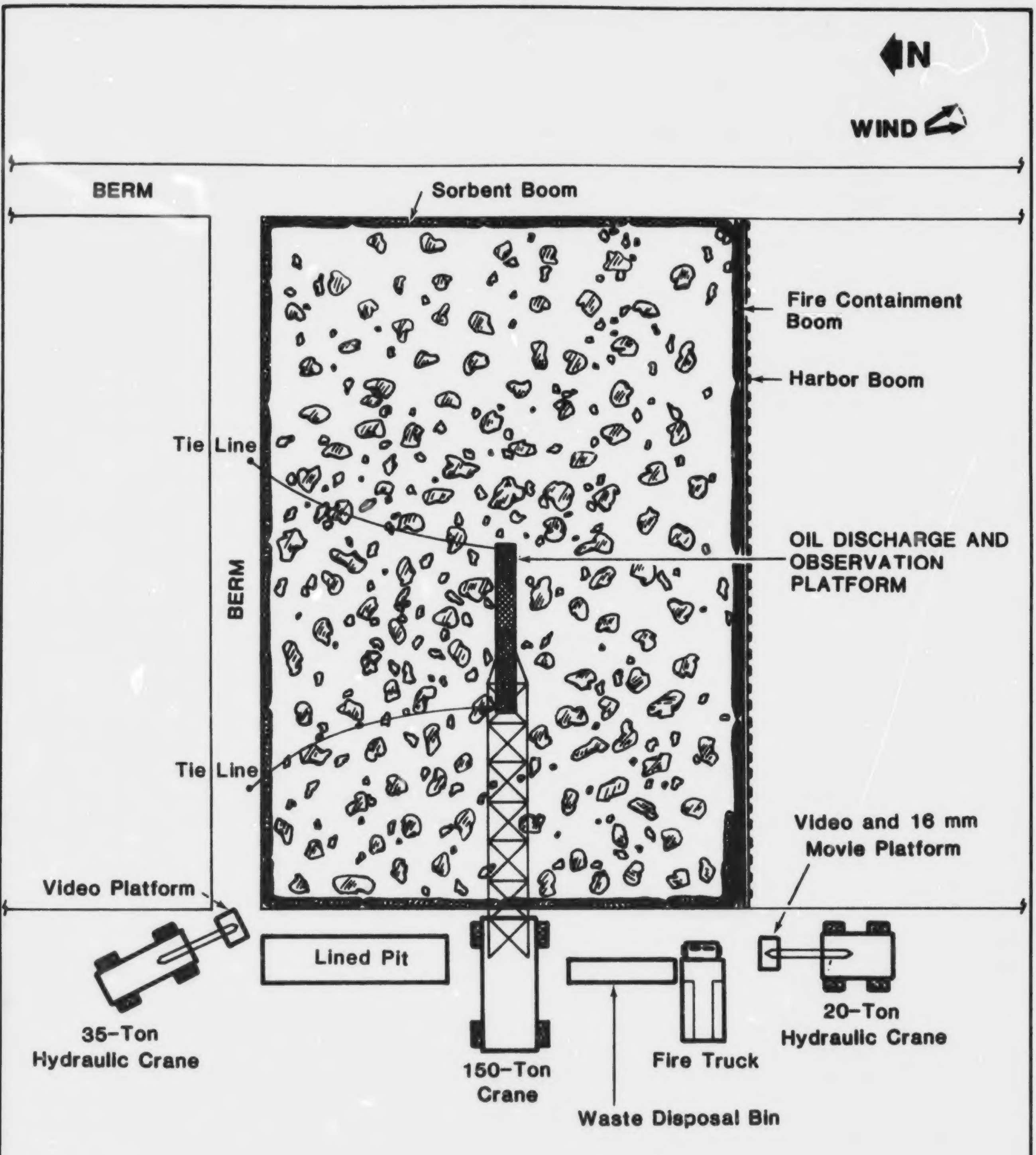
[3] The air-deployable igniter was developed in Canada and consists of gelled kerosene ignited by a solid propellent and held together by a wire-mesh enclosure fitted with flotation devices.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WIND
BERM
Sorbent Boom
Fire Containment Boom
Harbor Boom
Tie Line
OIL DISCHARGE AND OBSERVATION PLATFORM
BERM
Tie Line
Video and 16 mm Movie Platform
Video Platform
Lined Pit
35-Ton Hydraulic Crane
150-Ton Crane
Fire Truck
20-Ton Hydraulic Crane
Waste Disposal Bin

Figure 2 Plot Plan: Task 1, Tests 1 and 2

Test Conditions

Test 1 was completed under clear skies with air temperatures around 35°F and winds out of the north-northwest at 5 to 7 knots. The water temperature within the pit was measured at 33°F. Ice conditions in the area reached by the oil discharge and its subsequent spreads consisted of scattered, grounded ice pieces ranging from 1 to 6 feet in maximum linear dimension, with thicknesses of 2 to 4 feet (Photo 3). Some smaller pieces of floating ice (typically 2 to 12 inches) were scattered among the larger grounded pieces so that the overall ice coverage was 3 to 5 oktas.

Oil Behavior

Within 2 to 3 minutes following the initial release of the 36 gallons of crude oil (Photo 4), an elongated swath of oil 50 to 60 feet in length was created. The oil slick had reached equilibrium (i.e., it ceased spreading) with an average swath width between 15 and 25 feet, resulting in an estimated coverage of about 1,100 square feet (Photo 5). Assuming that approximately 50% of the surface area consisted of ice, the 36 gallons of oil spread over a 550-square-foot area would then represent an average thickness of about 0.11 inch. At this thickness, the oil was still black in color, with sharp clearly defined edges. The wind, though light was able to transport the oil slowly between the ice pieces, tending to elongate portions of the downwind end of the slick into long, meandering fingers of oil.

Ignition

Three air-deployable, floating igniters were released from the oil discharge platform over a 2½-minute period following the achievement of equilibrium (Photo 6). The first igniter flashed properly and ignited a portion of the slick; however, the flame did not propagate as quickly as desired. A second igniter malfunctioned, flashing itself out within about 20 seconds. The third igniter resulted in a rapidly expanding fire within a minute after its release (Photo 7), causing flame to spread downwind 80 to 100 feet from the ignition point within another 2 minutes.

Burning

Within 4 to 5 minutes following release of the first igniter, approximately 80% of the entire oil slick was involved in an intense fire. A small portion of the slick's sides was still unignited even though the oil was in direct contact with the center portion of burning oil. At the upwind end of the slick, there remained about 10 to 15 feet of slick still unignited as well.

The wind was sufficient to hold the upwind leading edge of the fire at a nearly fixed position, while moving the upwind oil slowly toward the fire's edge.

During the next few minutes the fire gradually spread sideways among the ice pieces, thus exposing more than 90% of the oil slick to flame. The oil along the edges, however, had been sufficiently heated by the fire that its reduced viscosity and resulting reduction in thickness could not support a sustained burn. The fire quickly diminished to a number of scattered pools of burning oil and became completely extinguished (naturally) within 6 to 7 minutes following release of the first igniter.

Post-Burn Conditions

Upon completion of the burn, an area approximately twice the slick size (at equilibrium) had been exposed to the oil and/or the burn residue. The increased areal exposure was primarily in the downwind region where burn residue was continuing to drift among the ice pieces. Most of the burn residue was being herded by the wind into concentrated mats of a sticky, tar-like substance that could be recovered easily using any number of mechanical removal techniques. The method selected during the demonstrations involved sorbent pads since they would facilitate a quantitative assessment of the amount of residue recovered. Some of the ice downwind of the fire had scattered patches of oil residue on its surface. Beyond the pit, signs of any fallout from the fire were not visually discernible.

Sampling and Cleanup

Stage agency representatives collected samples of the burn residue and of the oil that appeared to be partially burned. The results of any sample analyses should become available through the State of Alaska as part of its final assessment of the demonstration program.

The burn residue was cleaned up by eight men in approximately 1 hour. Considerable care was taken during the cleanup effort to recover all visible oil and burn residue from the water surface and the ice (Photo 8). Oiled ice surfaces were easily cleaned up by splashing water onto the oil or residue and then removing the material from the surrounding water with 3M-brand sorbent pads. All of the oiled sorbents were weighed (Photo 9) resulting in approximately 93 pounds of sorbent and 116 pounds of burn residue. The in-situ burning of crude oil without artificial containment therefore resulted in the elimination of 55% of the spilled oil.

Summary of Results

The results of Test 1 provide useful information in answering specific questions raised in the introduction to Task 1:

- A major portion of the crude oil released in Test 1 remained thick enough to support combustion.
- The oil slick was ignitable, requiring three individual ignition attempts with air-deployable igniters released by hand about 15 feet above the oil.

- Typically 80% to 90% of the slick surface became exposed to flame during the burning process.
- Burning efficiency was reduced somewhat at the edges of the slick as heated oil tended to spread more rapidly into isolated thin layers.
- This test, involving a relatively small quantity of oil and little, if any natural containment by ice, resulted in 55% of the oil being removed by burning.
- The burn residue remained on the water surface as a semi-fluid medium, easily flushed from ice surfaces and removed using sorbents.

4.1.2 Test 2: 288-Gallon Spill into Grounded Ice

Preparations and Procedures

The 288-gallon spill into grounded ice was conducted in the same pit on the afternoon of June 11 using the same pit layout as for Test 1 (Figure 2). The oil was held in a specially constructed tank, 17 feet long and 30 inches in diameter, mounted on the observation platform. For this test, the platform was moved over the pit at a rate of 0.3 feet per second for approximately 1 minute, while 288 gallons of fresh, degassed Prudhoe Bay crude oil were discharged from a spreader plate 2 to 3 feet above the water (Photo 10). All 288 gallons were thus released within a distance of about 20 feet. Videotapes, 16 mm movies, and 35 mm still photography were taken of the entire demonstration.

Test Conditions

Test 2 was carried out within a few hours of Test 1 under nearly the same environmental conditions. Air temperatures had increased slightly to around 36° to 38°F, while the winds remained from the north-northwest at 5 to 7 knots. Water temperature within the pit was still about 33°F, and the ice conditions were relatively unchanged. Slight melting of the ice surfaces had occurred during the first test; however, the ice coverage still consisted of 3 to 5 oktas of grounded ice.

Oil Behavior

Within 3 to 3½ minutes following the initial release of oil, all 288 gallons of crude oil had reached an equilibrium condition. The soil slick was black, with clearly defined edges over most of its periphery (Photo 11). Small regions of the slick's perimeter consisted of thinner light-brown films. Upon reaching equilibrium, the oil slick was nearly circular, with an average diameter of 100 feet. If, as in the previous case, we assume that 50% of the oiled surface area consisted of ice, the 288 gallons of crude oil would represent a total slick coverage of about 3,900 square feet. The oil would therefore represent an average thickness of 0.12 inches. This equilibrium thickness estimated in the smaller spill of Test 1.

Ignition

Within 1½ minutes after the slick reached equilibrium, the first air-deployable igniter was released from the suspended observation platform. The igniter functioned properly; however, it was poorly positioned on the upwind side of a piece of ice where oil could not move freely beneath the flame. After an additional 2½ minutes, a second igniter was released, and rapid ignition of the upwind portion of the slick resulted (Photo 12).

Burning

After ignition, the fire spread both downwind and crosswind, engulfing approximately two-thirds of the entire slick within 4 minutes following release of the second igniter (Photo 13). During the next 2 to 3 minutes, the fire grew and reached its maximum intensity where turbulent flames billowed 60 to 80 feet upward. At its maximum intensity the burning portion of the oil slick represented about 85% to 90% of its entire area. The outer edges of the slick at right angles to the wind (about 5 to 10 feet wide) remained unignited. These portions of the slick were heated sufficiently to cause spreading and therefore thinner films that would not support combustion. The intense period of burning persisted for a total of 6½ minutes and involved burning oil from the upwind edge to the extreme downwind edge. In the downwind region of the pit, the accumulation of burning oil resulted in a number of small though relatively persistent fires. As the flames rapidly subsided, partially burned upwind slicks and unburned oil at the extreme edges of the slick continued to drift among the ice to those smaller fires. Small, isolated fires continued to burn for approximately 5 minutes along the fire containment boom lining the downwind side of the pit.

Post-Burn Conditions

As the intense portion of the burn ended the areal extent of the burned and unburned oil residue was slightly larger than the area of the slick when it reached equilibrium prior to ignition. Although there was some tendency for heated oil along the edges to spread outward during the fire, the inward rush of air due to thermal updraft appeared to reduce the tendency for expansion of the oil and its burn residue. As in the previous test, the remaining oil and residue were of a semi-fluid consistency that permitted its removal with sorbent pads. A few small areas toward the center of the burn consisted of thicker, rubber-like patches that were closer to a plastic condition. The ice pieces in the center of the burn area had light coatings of burned oil with thicker patches as well. In both burn tests, the coatings of oil on the ice were spotty and surficial. There was no significant penetration of the ice surfaces with oil or fallout residue.

Sampling and Cleanup

As in Test 1, State representatives collected samples and handled laboratory arrangements. All cleanup was once again accomplished with eight men; however, about 2 hours were required for pickup of all oil and residue. This is not necessarily representative of the time it would normally take to clean up an actual spill of this size. The field crew in this demonstration was taking considerable time to complete a careful, accurate count of the number of sorbents used to collect all of the residue.

All ice surfaces were once again cleaned by splashing water to remove the residue and then using sorbents to pick it up. A total of 105 pounds of sorbent was used to remove all collectible oil and residue. With approximately 306 pounds of oil and burn residue collected, the in-situ burning of a larger volume of oil in this test (again without artificial containment) resulted in the elimination of 85% of the spilled oil.

Summary of Results

The results of this test provide the following answers to specific questions raised in the introduction to Task 1:

- The majority of oil spilled during Test 2 once again remained thick enough to support combustion.
- Igniters released by hand about 15 feet above the oil were successful in igniting the oil slick. Two igniters were required in this test.
- Approximately 85% to 90% of the oil slick surface became exposed to flame during the burning process.
- Burning efficiency was slightly influenced by the tendency for heated oil to wander away from the heavier oil conentration, however, thermal updraft effects from a fire of this magnitude appeared to overcome the spreading and thus limit the areal extent of the fire and its burn residue.
- In Test 2, the burning efficiency was determined to be about 85%. Since some burning continued after oil began to be herded against the downwind side of the pit, this burning efficiency might be reduced a few percent for a comparable burn test where wind was not herding the oil against a barrier.
- The burn residue in this test remained on the water surface as a semi-fluid medium with a few patches of thicker, rubber-like material. All cleanup could be accomplished effectively using the same flushing and/or sorbent removal techniques as in Test 1.

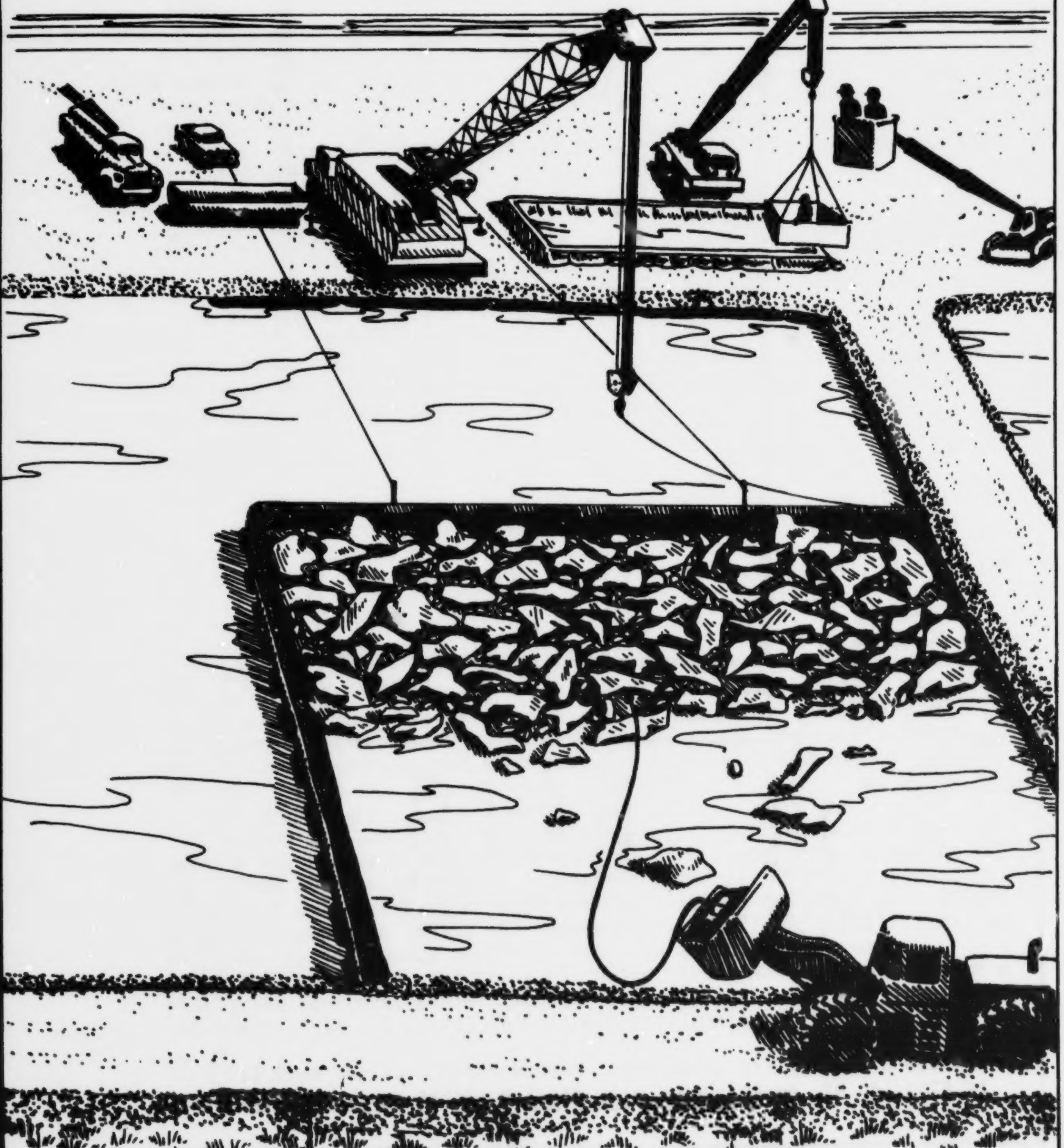
4.1.3 Test 3: 36-Gallon Spill into Floating Ice

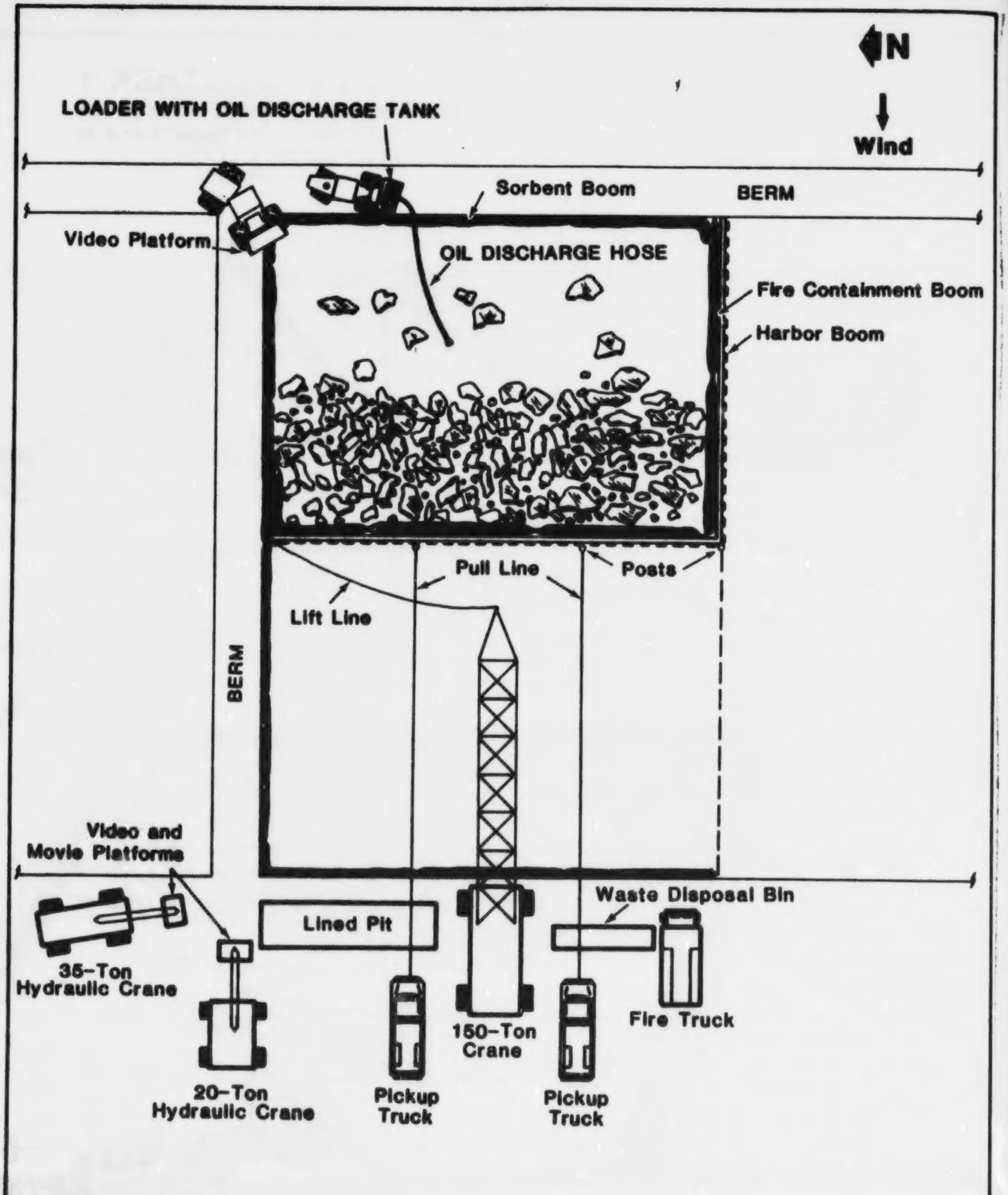
Preparations and Procedures

After the residue was recovered from Test 2, more water was pumped into the test pit from an adjacent drilling mud disposal pit.

TASK 1

In-Situ Burning of Oil in Scattered Ice
(Tests 3 and 4)

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Sorbent Boom
BERM
Video Platform
OIL DISCHARGE HOSE
Fire Containment Boom
Harbor Boom
Pull Line
Posts
Lift Line
BERM
Video and Movie Platforms
Waste Disposal Bin
Lined Pit
35-Ton Hydraulic Crane
20-Ton Hydraulic Crane
Pickup Truck
150-Ton Crane
Pickup Truck
Fire Truck

Figure 3 Plot Plan: Task 1, Tests 3 and 4

On June 12, when the ice was floating, approximately half of it was removed from the test area by two Caterpillar 966 loaders, while the remaining ice cakes were pushed to the upwind (east) half of the pit. The ice was restrained from moving downwind by sections of Harbor Dike boom and Shell fire containment boom placed adjacent to each other across the pit. Metal poles were driven into the bottom of the pit to hold the boom in place while the wind piled the ice against it (Figure 3).

A barrel containing the degassed Prudhoe Bay crude oil was supported in the bucket of a 966 loader on the upwind shore. A hose, with sorbent boom for flotation, was extended from the barrel to the upwind edge of the concentration of ice pieces. State and industry observers watched the demonstration from an observation platform located at the side of the pit.

A 45-foot-long slick was created by manually pulling the floating hose toward shore while the oil was pumped at a rate of 15 gallons per minute for a little over 2½ minutes. The oil was observed to float in the open water upwind of the ice and among the closely packed ice pieces along the upwind edge. The 150-ton crane was used to pull the ice-restraining Harbor boom away from its pre-spill position. Pickup trucks pulled the poles out that held the Harbor boom in the center of the pit. When the Harbor boom was removed, the ice and oil moved with the wind toward the open-water portion of the pit.

Results

Test 3 was conducted under clear skies with air temperatures around 36°F and winds from the east at 5 to 10 knots. The water temperature remained at about 33°F, while ice conditions consisted of wind-packed pieces ranging from a few inches to several feet (Photo 14). During the release of oil in Test 3, several unplanned-for conditions influenced the expected chain of events. First, the positioning of support equipment on the eastern side of the pit and the proximity of that equipment to the oil slick resulted in wind-induced surface eddies that quickly broke up the oil slick and spread it into relatively thin films upwind of the ice. Because of the unusual behaviour of the oil, agency representatives requested a temporary delay of ignition even though equilibrium conditions had been achieved for the darker oil up against the ice.

During the subsequent period of observation, the oil continued to move in the random directions in the lee of the equipment alongside the pit. Then when igniters were dropped into the oil upwind, irridescent films with small streaks of dark oil could not be ignited. Only after several attempts to ignite the darker pools of oil among the ice failed, did industry and agency personnel begin to question the seeming non-combustibility of the crude oil being used. Numerous attempts were made using igniters, aerial signal flares, road flares, gasoline-soaked rags, etcs. In all cases, the oil was not ignitable.

Oil from the vacuum truck used for storing oil in Test 3 was then sampled, and various ignition tests were conducted on the oil both at the test site and in a laboratory under controlled conditions. All tests revealed that the oil released during Test 3 was significantly void of its lighter, more volatile components. Laboratory flash point tests on the crude oil indicated values in excess of 30°F instead of the usual flash point of about -20°F. This "highly weathered" condition explained why the oil slicks could not be ignited. The cause of this condition is still uncertain; however, one possible cause is that a substantial vacuum may have been maintained over the oil while being stored overnight in the vacuum truck. The oil would have been artificially weathered as the lighter volatiles were extracted from it.

Although the oil did not ignite, it was possible to make some important observations. It was noted, for example, that:

- The presence of ice, particularly large pieces and tightly packed brash ice, is of significant value in providing a barrier during the herding of oil by wind (Photo 15).

- While Prudhoe Bay crude oil quickly establishes an equilibrium thickness on the order of a tenth of an inch, wind effects can reduce an uncontained oil slick to irridescent films and sheens. The extent of spreading and time required to produce such thin films is, of course, dependent on the volume of oil spilled, the wind and sea state, the type and amount of ice present, etc.

- The thinner oil films typically moved under the influence of winds at between 25% and 50% faster than the large pieces of ice in the pit (i.e., those between 1 and 3 feet across). The smaller pieces of ice (typically 6 inches or less) had drift rates that were nearly equal to the oil drift rate. In all cases the oil drift rate was predictably between 3% and 4% of the wind speed.

- Early containment (with ice or boom) and prompt ignition of an oil slick, especially for small spills, are desirable for efficient in-situ burning in order to minimize spreading and evaporation.

4.1.4 Test 4: 288-Gallon Spill into Floating Ice

Preparations and Procedures

Test 4, which was conducted on June 12, 1983, involved the same basic preparations and procedures used in Test 3 earlier the same day. Floating ice was once again held in position by containment boom in the upwind half of the pit. The ice, however, still contained an estimated 30 gallons of highly weathered oil from Test 3. Photo 16 shows the concentration of ice and weathered oil prior to the release of 288 gallons of degassed Prudhoe Bay crude oil.

The same 17-foot-long tank used in Test 2, but containing a fresh supply of crude oil, was suspended from a 966 loader at the upwind (east end) of the pit. The oil was discharged through a floating hose positioned upwind of the ice. As the oil was released over a 1½ minute period, the ice-restraining booms were lifted, allowing the oil and ice to mingle while drifting toward the west end of the pit.

When equilibrium conditions were achieved (i.e., oil spreading ceased), a helicopter was used to deploy the same kind of igniters used in Tests 1, 2 and 3. Videotapes, 16 mm movies, and 35 mm still photography were used throughout the demonstration to document the nature and extent of spreading, the ignition and burning of the oil, and the subsequent cleanup.

Test Conditions

Oil was released during Test 4 at approximately 6 p.m. Winds had increased to between 16 and 18 knots from the east, while air temperatures remained at about 36° to 38°F. The wind-packed ice held back by boom consisted of ice pieces ranging from a few inches to several feet across (Photo 16). The variability in ice sizes was desirable so that upon release of the restraining boom, the ice would move with the wind at different speeds, allowing for a variety of oil/ice interactions.

Oil Behavior

Shortly after the oil release began, crude oil drifted at between 1/2 and 3/4 foot per second toward the upwind edge of the trapped ice. When equilibrium was achieved within approximately 2 minutes, the oil-covered water upwind of the ice zone covered approximately 3,500 square feet. The oil therefore achieved an average thickness of 0.13 inch. During the initial spreading, oil was held in place with minimum penetration of the ice zone; however, as the ice began to spread out and move downwind, the oil was blown into the ice field. As in the previous test, the oil was observed moving somewhat faster than the largest pieces of ice. In some cases, thin films moved at up to 1½ times the drift rate of the ice.

Ignition

The first igniter was released from a helicopter passing over the slick from an altitude of about 50 feet. The igniter was released accurately into its target area upwind of the ice zone; however, the wind blew it into a region where the oil concentration was insufficient to initiate combustion. Within 2½ minutes a second igniter was released from the helicopter, this time landing within the thicker, stable portion of the slick. Within a minute following release of the igniter, the oil slick was ignited and flames were propagating rapidly downwind.

Burning

Within 2 minutes following release of the second igniter, a major portion of the crude oil slick was engulfed in flame. The fire grew to an intense burn lasting approximately 5 minutes. During this period, the burning oil spread among the ice cakes and ignited other adjacent slicks as it moved downwind (Photo 17). The wind speed was high enough to keep flame from propagating upwind even though significant volumes of oil still existed along the north-east (upwind) portion of the pit.

As the flames gradually diminished to a number of scattered, smaller fires along the downwind side of the pit, oil continued to bleed from pockets and crevices where it had become temporarily trapped in ice upwind. The oil gradually drifted toward the burning pools among the ice, where it, too, became ignited (Photo 18). Most of the self-sustaining fires were extinguished naturally about 24 minutes after ignition began. The ignition of oil trapped in ice and along the sides of the pit, however, continued into the evening as various secondary burn techniques were attempted.

Post-Burn Conditions

Conditions following the natural extinction of fires associated with the second igniter involved a densely packed oil-and-ice matrix typically 10 to 15 feet wide along the downwind (western) side of the pit. Ice pieces varied in size, although their surface conditions remained relatively unchanged. Some thin films still remained on open water upwind, but these slicks were still being herded by the wind toward the oil/ice matrix. Some of the larger pieces of ice had patches of oil residue on their surfaces; however, beyond the pit, signs of any fallout from the fire were not visually discernible.

Cleanup

Agency representatives agreed that because a portion of the burn included wind-herding of the slick against the downwind side of the pit, it would be instructive to remove as much oil as possible by burning before any mechanical removal techniques were used. Standard air-deployable igniters, modified igniters (with attached canisters of diesel), weed burners, and low pressure propane torches were used from the shoreline and from small boats. The use of low-pressure torches, involving minimal disruption of the oiled surface being ignited, was found to be one of the most effective means of eliminating small pockets of oil and partially burned residue.

Following the efforts to remove oil by in-situ burning, the field crew once again used sorbents to remove as much of the remaining residue as possible. Assuming that the test involved approximately 30 gallons of crude left in the ice from Test 3, and that the additional 288 gallons of fresh crude brought the total for Test 4 to 318 gallons, the burn residue amounted to about 27% of the initial oil volume. The burn efficiency for Test 4 (including secondary burn techniques) was therefore about 73%.

Summary of Results

Test 4 provided the following additional information with respect to the questions raised in the introduction to Task 1:

- The crude oil spilled into floating ice under fairly strong wind conditions still remained thick enough to support combustion.
- The oil slick was ignitable using two air-deployable igniters released from a helicopter.
- Because of the higher winds (16 to 18 knots), flame propagation at right angles to the wind was reduced. While flame could not spread upwind, the stronger wind helped herd oil to downwind ignition sources.
- The movement of oil through the ice cakes during burning did not result in isolated patches of oil being removed from the fire. The strong winds, in fact minimized the escape of heated oil at the edges of the fire by herding oil and smaller ice chunks against the larger ice pieces downwind.
- Immediate in-situ burning with igniters dropped from a helicopter, together with backup burning techniques to support the combustion process, resulted in a burn efficiency near 73%.
- Most of the burn residue could be removed with conventional mechanical removal techniques including sorbent and pitchforks covered with fine, wire-mesh screens.
- Igniters can be effectively deployed from helicopters by personnel with minimal training.

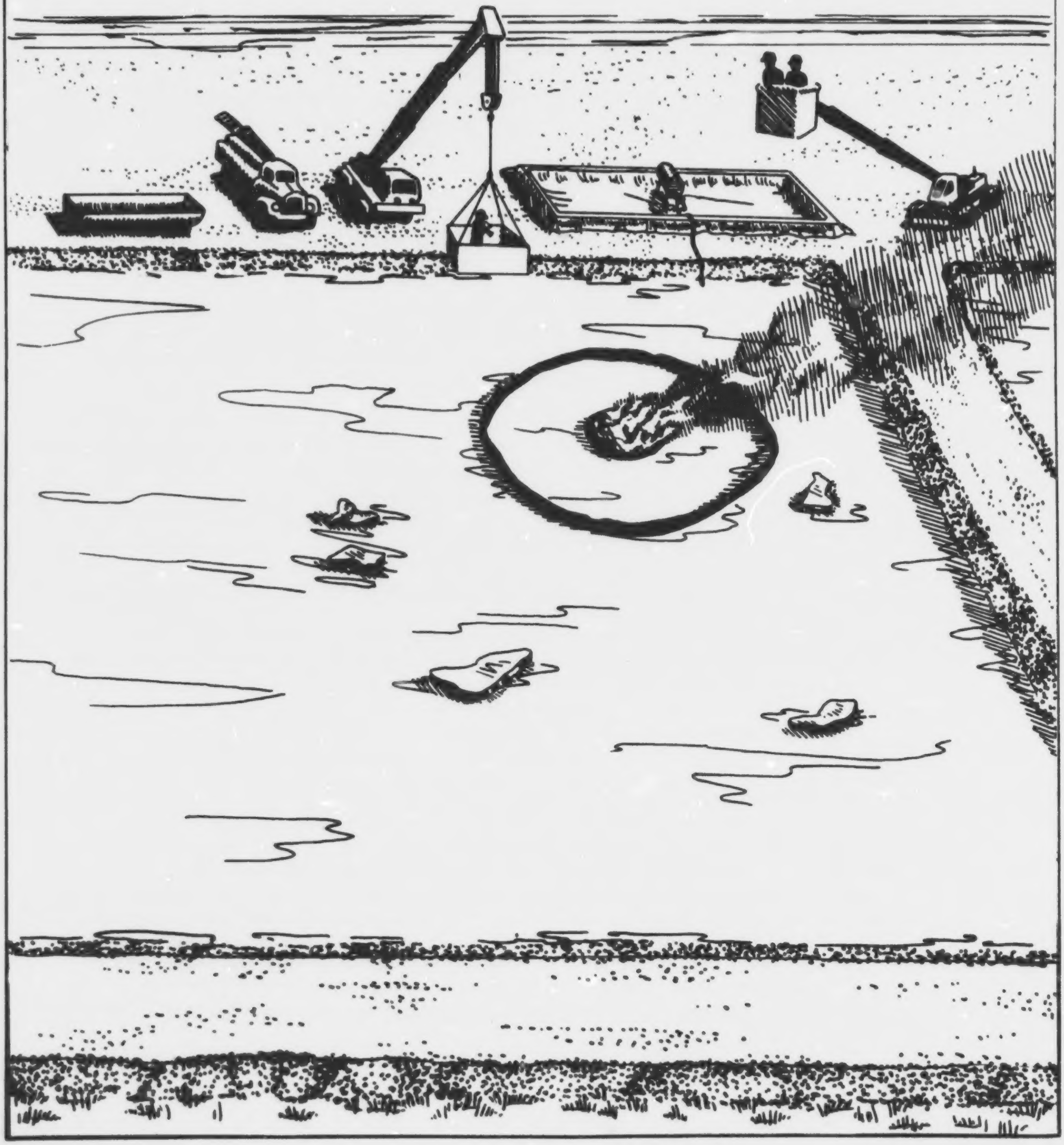
4.2 Task 2: Burning of Oil Inside Fire Containment Boom

Task 2 consisted of tests of the survivability of Shell Oil Company's first generation fire containment boom in the same pit used for Task 1. Following the first two tests on June 13, 1983, several additional tests were conducted in June and July to improve the boom's structural characteristics and to provide additional information on its survivability during longer periods of exposure to burning oil.

The objective of these tests was to demonstrate the feasibility of containing the burning crude oil with a relatively inexpensive, lightweight and flexible boom constructed from commercially available materials. Other fireproof booms have been developed in Canada, and while these systems do offer advantages under certain conditions, their use in some oil spill scenarios for Alaskan operations in the Beaufort Sea is limited because of weight, strength, and cost considerations. Further demonstrations of the Shell fire containment boom and its performance during actual deployment, containment, and removal activities at sea were carried out during Task 6 and are described in Section 4.6.

TASK 2

Burning of Oil Inside Fire Containment Boom



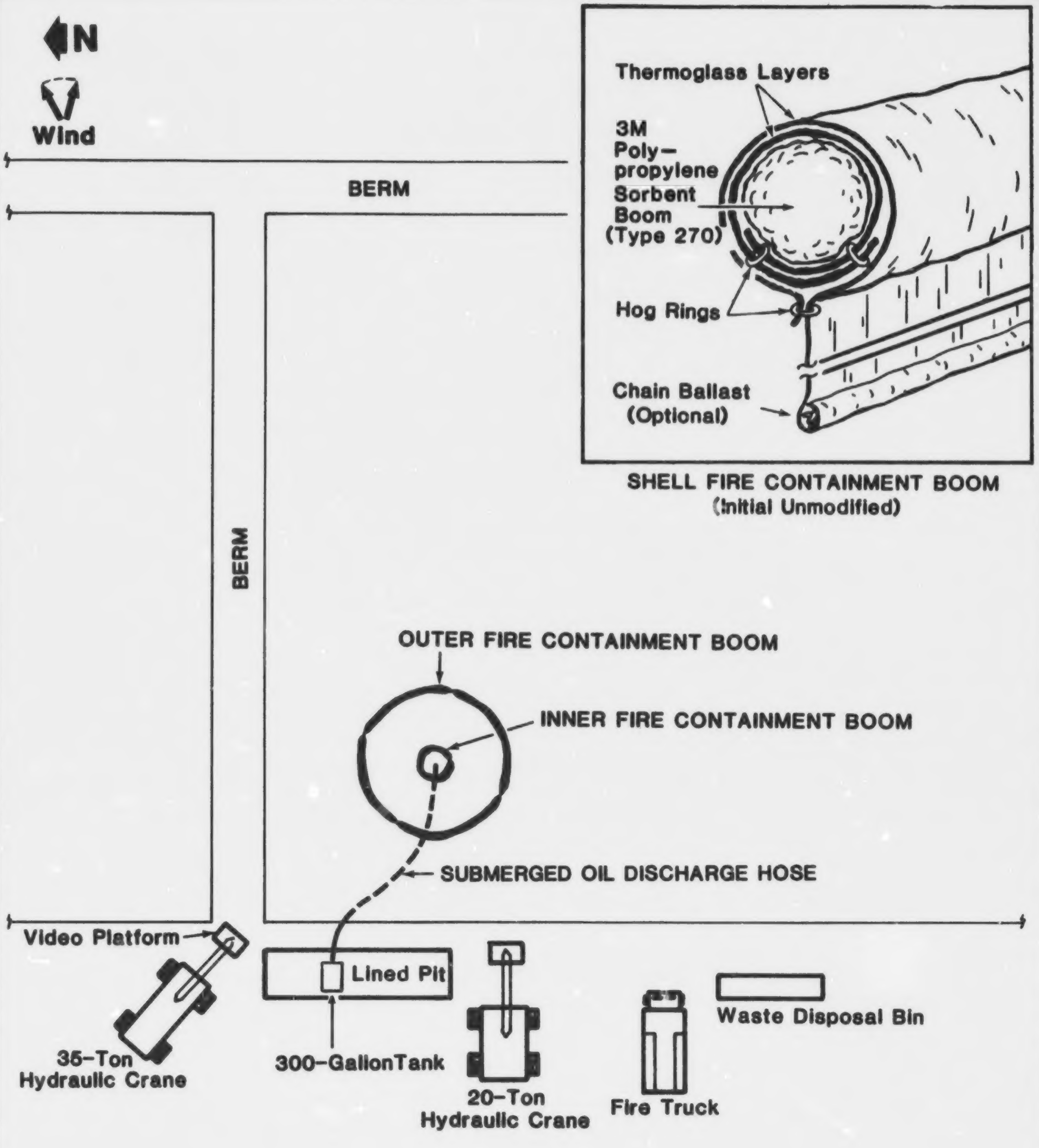

N
Wind
BERM
BERM
Thermoglass Layers
3M Poly-propylene Sorbent Boom (Type 270)
Hog Rings
Chain Ballast (Optional)
SHELL FIRE CONTAINMENT BOOM
(Initial Unmodified)
OUTER FIRE CONTAINMENT BOOM
INNER FIRE CONTAINMENT BOOM
SUBMERGED OIL DISCHARGE HOSE
Video Platform
Lined Pit
35-Ton Hydraulic Crane
300-GallonTank
20-Ton Hydraulic Crane
Fire Truck
Waste Disposal Bin

Figure 4 Plot Plan: Task 2, Tests 1 and 2

The Task 2 demonstration was designed to answer the following specific questions:

- Will the fire containment boom keep crude oil contained without leakage while suitable oil thicknesses are developed for combustion?
- Will the fire containment boom be able to survive the intense heat generated by burning crude oil?
- Will the boom be reusable?

4.2.1 Test 1: Single Burn

Preparations and Procedures

Following Task 1, the ice was cleared from the northwest corner of the pit at East Dock by two 966 loaders. Two concentric fire containment booms were then anchored in position (Figure 4). The boom to be tested (the inner boom) had an inside diameter of 8 feet. The outer boom was provided as a backup barrier to contain any oil that might spread beyond the first boom. Industry and agency representatives observed the demonstration from the ground at the edge of the pit and from platforms suspended from cranes near the edge of the pit.

Thirty-four gallons of fresh, degassed Prudhoe Bay crude oil were then poured into the center ring to form a 1-inch thick oil layer. The oil was ignited by a torch made from oil-soaked sorbent material tied to a pole. The entire demonstration was documented on videotape, 16 mm movies and 35 mm slides taken from the ground and from the elevated platforms. The length of time it took for the fire to burn out was noted. One video camera with a built-in stopwatch recorded real time superimposed on its screen for subsequent study and documentation purposes.

After the fire had burned out, samples were collected by State representatives for analysis. The burn residue was carefully collected on sorbent pads, placed in plastic bags where the water was allowed to drain off, and then weighed. The amount of burn residue was then determined and used to estimate the burn efficiency.

Results

At the start of Test 1, a light breeze of 3 to 5 knots was blowing from the west. The air temperature was about 40°F, and the water in the pit remained at about 33°F. The 1-inch layer of oil in the 8-foot-diameter ring was allowed to sit for approximately 20 minutes prior to ignition. During this time, there were no signs of oil leakage through or beneath the boom; however, a very small quantity (less than ½ gallon) passed beneath the inner boom during the pouring process.

Upon ignition, the fire spread over the entire area within the ring, building to an intense blaze 20 to 25 feet high within 1½ minutes (Photo 19). The fire continued to burn at about the same intensity for nearly 10 minutes, after which it quickly died out. The last 2 minutes of the burn were punctuated by loud bubbling and popping sounds accompanied by an occasional burst of flaming oil droplets. When the fire burned out, the surface within the ring was covered with a frothy, foam-like layer of burn residue. This layer then settled down to a dark, black, viscous layer about 0.1-inch thick (Photo 20).

Outside the inner test boom, a thin brown layer with black streaks had developed downwind of the fire. This slick (½ gallon or less) was undoubtedly a result of the small quantity released during the pouring process and during the splashover phase of the final minute or two during burning.

The burn residue was recovered using 3M sorbent pads weighed before and after the collection process. It was found that about 10% of the original weight of oil used still remained after burning. Therefore, the burning of a 1-inch layer of crude oil in Test 1 accounted for about 90% of the original volume of oil in less than 10 minutes.

Following the burn, an inspection of the boom revealed no noticeable change in buoyancy and no damage of any kind to its surface materials. As in most tests of the boom prior to this demonstration, the upper surface of the external Thermoglass layer was discolored on the downwind side of the ring. The fire containment boom was still flexible, buoyant, and fully capable of containing additional oil.

In summary, this test demonstrated that:

- The fire containment boom would hold oil at least 1 inch in thickness without leakage during calm-water conditions.

- The boom is capable of withstanding the heat generated by a single burn of crude oil 1 inch thick, in this case with an exposure time of about 10 minutes.

- The burning oil contained by the boom resulted in the elimination of about 90% of the oil exposed to combustion.

- Following the burn, the boom showed no signs of destruction or stress of any kind. A discoloration of the boom's upper surface was apparent, but it was still flexible and structurally sound. The same boom was then reused in Test 2.

4.2.2. Test 2: Continuous Burn

Preparation and Procedures

Following the cleanup of residual oil from Test 1, all equipment was checked in preparation for the 1-hour continuous burn of crude oil inside the same test section of fire containment boom. A 300-gallon tank on a 6-foot-high stand was used along with a 1½-inch-diameter hose to gravity-feed oil from the tank to a submerged vertical pipe set in the center of the inner boom. A valve at the tank was present to provide the flow rate of approximately 2½ gallons per minute to the area within the boom. All other preparations were the same as for the pervious single-burn demonstration.

As oil began to flow into the region enclosed by the inner boom, the oil was ignited using a torch made from oil-soaked sorbent pads tied to a pole. The entire 1-hour burn was observed by industry and agency representatives, while videotapes, 16 mm movies, and 35 mm slides were used to record the test.

Upon completion of the demonstration, the burn residue was once again collected and weighed. The boom was brought to shore, cut open and examined by industry and agency observers. Samples of the outer and inner layers of fabric were removed and stored for laboratory analysis.

Results

During Test 2, environmental conditions remained basically the same as in Test 1; however, the wind shifted and increased to approximately 10 to 12 knots from the southwest. As oil began to flow from the pipe positioned at the center of the ring, it was ignited immediately. Since oil was continually fed to the fire at a rate of 2½ gallons per minute, the burn rate was safely within the maximum burn rate of a little over 3 gallons per minute for an 8-foot-diameter area based on the previous test[1].

Following ignition, the burning oil filled the inner ring and maintained a constant fire typically 10 to 20 feet in height. Throughout the first half hour of the burn, the fire containment boom showed no significant change in shape or condition. However, at about 34 minutes following ignition, the downwind (northeast) side of the boom began to lose freeboard (Photo 21)[2]. At about 47 minutes into the burn, the downwind side of the boom had lost sufficient freeboard to allow some oil to escape. After 57 minutes, the fire had spread from the initial containment area and began burning the oil that had accumulated against the backup fire containment boom. Photo 22 was taken 1 minute before the 1-hour burn was complete. Approximately one-third of the downwind side of the inner boom was completely submerged, and oil and burn residue continued to drift toward, and be contained by, the backup boom.

With shutdown of the oil supply after 1 hour, the fire was quickly extinguished as oil thicknesses dropped below the 0.05 to 0.1-inch thickness required to sustain combustion. There was relatively little oil and burn residue left anywhere within the boomed burn area. The waters surrounding the backup boom were clean and showed very little indication of fallout or splashover. After the burn residue was collected with sorbents and the amount collected was weighed, a burn efficiency of 95% was determined for the 150 gallons of oil released during the 1-hour burn.

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[1] The 1-inch-thick pool of oil in Test 1 involved the elimination of 30.6 gallons (90% of 34 gallons) in about 10 minutes, or about 3.1 gallons per minute.

[2] Numbers in the lower right-hand side of the photo indicate date and time (i.e., July 13, 11:35 a.m.).

When the inner boom was retrieved for inspection, it was found that the boom's two layers of Thermoglass were still intact but that its polypropylene core of 3M sorbent boom had melted on the downwind side. The outer layer of Thermoglass had been sufficiently charred that it could be broken and torn easily by twisting. The inner layer, however, was in good condition all the way around the boom and showed no sign of destruction or of becoming brittle. Photo 23 shows the deterioration of the outer cloth layer and the survival of the inner layer.

When the inner Thermoglass layer was cut, approximately two-thirds of the inner core of 3M sorbent boom was found to be melted into a solid plastic mat. This degree of melting accounted for the loss in buoyancy of the boom and the eventual sinking of its downwind side. This type of melting and sinking problem had never been encountered in any of Shell's boom development tests prior to this pit test. It was therefore suspected that the water in the pit might have contributed to the unusual behavior of the boom. It was conceivable that the suspended solids (measured in excess of 2,000 parts per million) might have altered the wicking action of the Thermoglass and therefore its self-cooling behaviour in protecting the boom's inner core. Several samples of the inner and outer layers of the Thermoglass covering were therefore removed for subsequent laboratory analysis.

4.2.3 Follow-Up Tests

During the 3 to 4 weeks following completion of Task 2, Tests 1 and 2, work continued at Prudhoe Bay to test the fire containment boom using sea water in a tank while maintaining all other conditions as encountered in Test 2. Simultaneously, modifications were made to simply reinforce the boom for aerial deployment purposes and to provide additional buoyancy for stability and wave-riding performance (Photos 24, 25 and 26). Seven burn tests in sea water were conducted both in the original design configuration (as in Test 2) and in various modified forms, including the use of two 3M sorbent booms side by side for buoyancy instead of one (Figure 5). These burns consisted of single burns of a 1-inch oil layer and continuous 1-hour oil-feed burn as before (Photos 27, 28 and 29). In all tests, the booms (unmodified and modified for structural purposes) performed without the melting and sinking experienced in the pit test.

These follow-up tests, together with the results of detailed laboratory analyses of the pit water and Thermoglass samples, offered substantial evidence that the melting and sinking problem in Test 2 was in fact a result of the water quality during that test. For example, a microscopic examination of the cloth fibers on the downwind side of the boom revealed translucent particles (2 to 20 microns) numbering up to

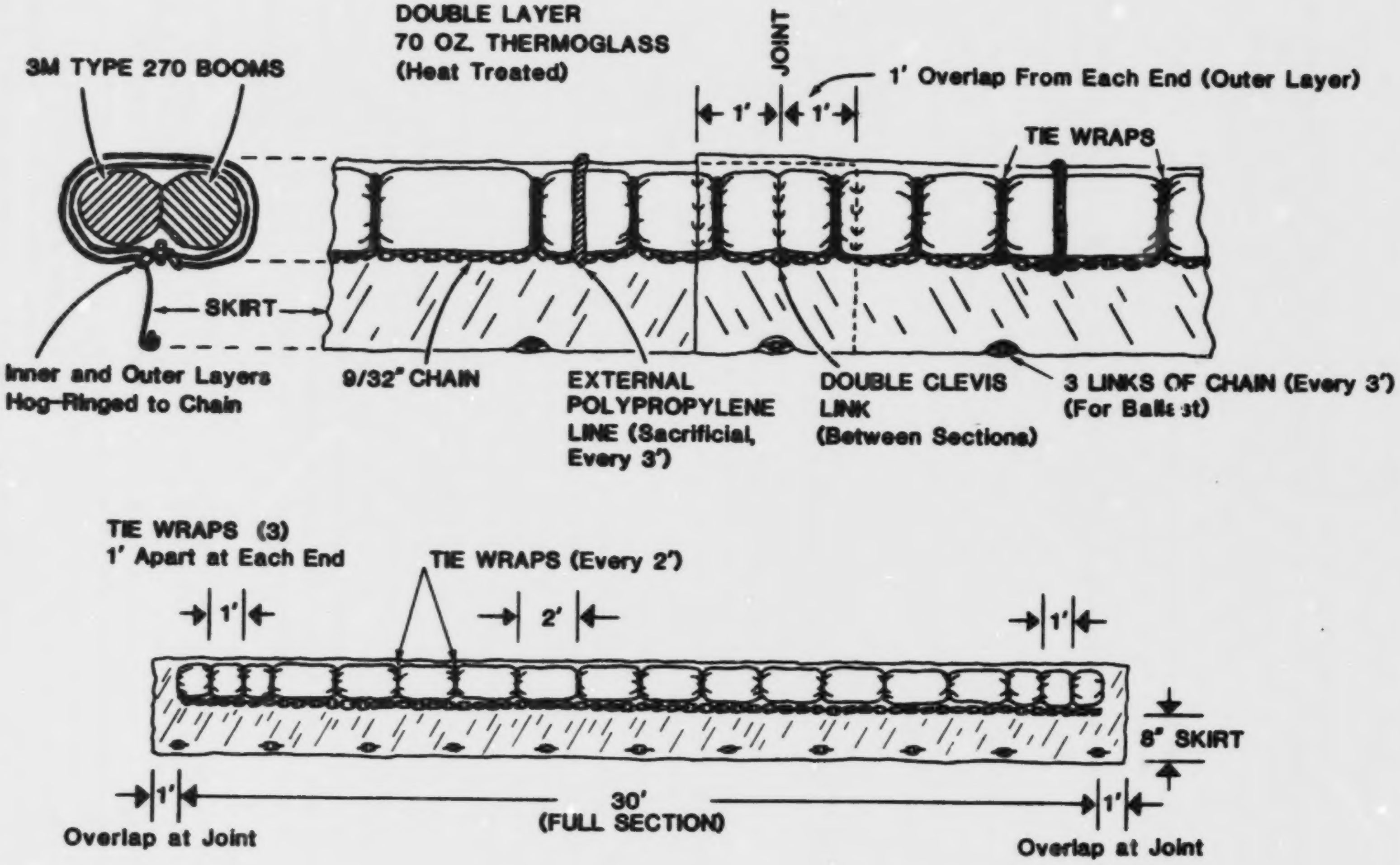

3M TYPE 270 BOOMS
DOUBLE LAYER
70 OZ. THERMOGLASS
(Heat Treated)
JOINT
1' Overlap From Each End (Outer Layer)
1'
1'
TIE WRAPS
SKIRT
Inner and Outer Layers
Hog-Ringed to Chain
9/32" CHAIN
EXTERNAL
POLYPROPYLENE
LINE (Sacrificial,
Every 3')
DOUBLE CLEVIS
LINK
(Between Sections)
3 LINKS OF CHAIN (Every 3')
(For Ballast)
TIE WRAPS (3)
1' Apart at Each End
TIE WRAPS (Every 2')
1'
2'
1'
8" SKIRT
1'
30'
(FULL SECTION)
1'
Overlap at Joint
Overlap at Joint

Figure 5 Details of Modified Shell Fire Containment Boom
(As Modified for Task 2 Follow-up Burns and Task 6 Deployment)

237,000 particles per square inch. This compared with 2,500 particles per square inch for a clean, control piece of the same cloth. Further tests of the contaminated cloth showed positive results for the presence of bentonite, a mineral commonly used in drilling muds.

In order to be confident of the structural characteristics of the boom to be used in the Task 6 demonstration, several helicopter lifts were conducted in early July. When the final boom design configuration was identified, a 30-foot section was placed in a circle and burn-tested for 2 hours with a continuous supply of Prudhoe Bay crude oil. As witnessed by State agency reprsentatives, the boom survived the 2-hour test without destruction of its surface layers or its core.

4.3 Task 3: Operation of ARCAT in Broken Ice

During Task 3, ABSORB's catamaran skimming vessel, the *ARCAT*, was operated in a variety of ice conditions and in open water to demonstrate its potential in responding to an oil spill in the Arctic (Photo 30). With the vessel operating in ice-infested waters (7 to 20 feet deep) north of West Dock, the *ARCAT's* stability, maneuverability and speed were observed by industry and agency representatives. These operating characteristics were examined during skimming with the *ARCAT's* rope mop recovery system and during rapid transit without skimming. The 65-foot long vessel's capabilities were also demonstrated as it activated its dispersant spray booms (using sea water only) and its fire monitors (Photo 31). The *ARCAT's* overall utility and versatility as an offshore logistical support unit, dispersing platform, and oil recovery vessel were tested and witnessed by State, Federal and North Slope Borough representatives over an 8-hour period on July 21, 1983.

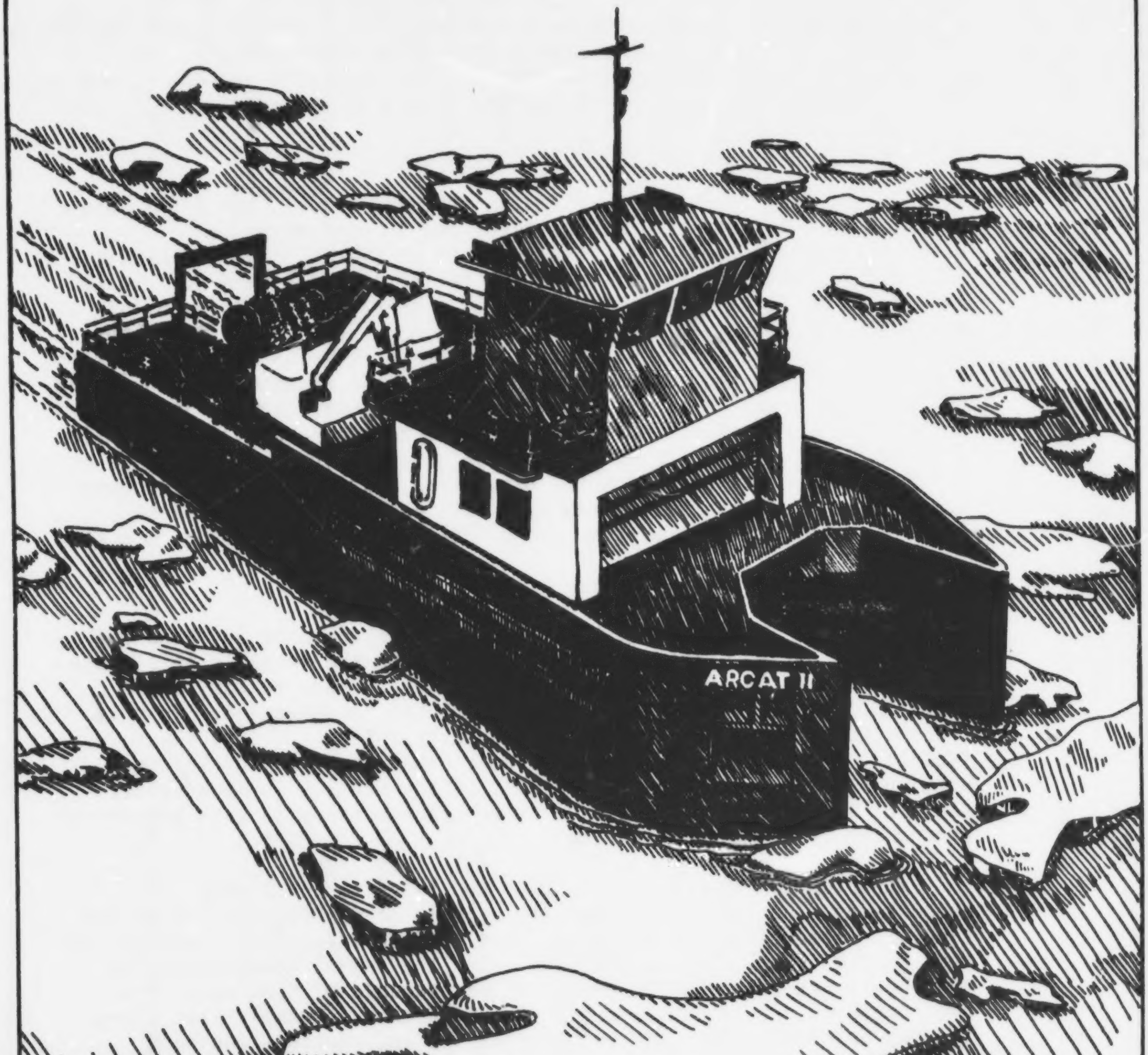
4.3.1 Maneuverability and Speed

The *ARCAT* functioned without mishap or breakdown of any kind for a full 8-hour period. The operation demonstrated the vessel's ability to push through broken ice, and in many cases break decayed ice, while transiting at 1/2 to 1 knot in 6 to 7 oktas of ice coverage. In this transit mode the vessel encountered dense brash ice and ice cakes typically 2 to 30 feet in maximum linear dimension with thicknesses varying between 6 and 36 inches. Most of the ice was in an advanced stage of melt so that it could be broken as necessary to pass between or around the vessel's catamaran hull.

When ice pieces too large and/or too thick to break were encountered, the *ARCAT* was generally capable of pushing the ice to one side. In some cases the *ARCAT* was able to push large floes (150 to 200 feet across) slowly out of the way. When the vessel encountered ice that could not be broken or moved, it was capable of turning within its own length to provide a new angle of approach or to simply exit along its own original path. The maneuverability and station-keeping characteristics of the *ARCAT* were evident as the vessel was used to provide and maintain optimum positioning at the edge of large ice floes and within heavy ice concentrations.

TASK 3

Operation of ARCAT in Broken Ice



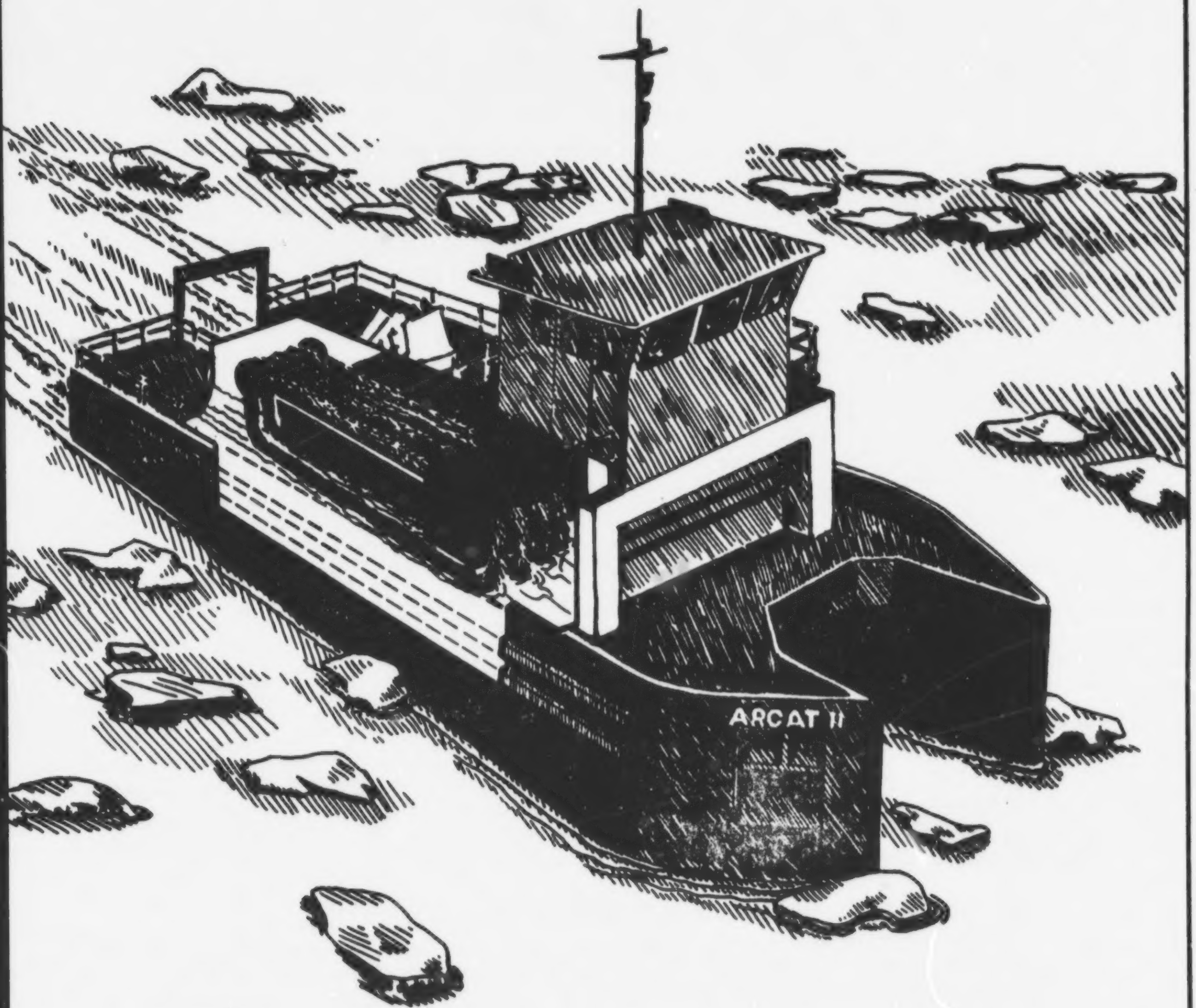


Figure 6 View of ARCAT with Cutaway of Hull (Task 3)

As ice concentrations began to open up (say, 2 to 10-foot pieces with coverages between 3 and 5 oktas), it was possible to increase the vessel's speed to between 1 and 2½ knots. There was sufficient time for the ARCAT to manueuver around any pieces that could damage the hulls or become lodged between them. Several attempts were made to deliberately block the entry space between the vessel's hulls with ice slightly larger than the 6-foot opening. However, it was found that the ice would typically crack, tilt, and/or have its edges shaved off by the hulls as the pressure of the water forced it toward the rope mop recovery area.

During open water and in light-ice concentrations (i.e., 1 to 2 oktas), the ARCAT could be operated for extended periods at between 5 and 7 knots. Full power could be used to achieve speeds in excess of 8 knots for shorter periods of performance.

4.3.2 Recovery Potential

The ARCAT has two built-in oil recovery systems. Its primary mode of recovery consists of two CS1 2-29 wringer assemblies with four continuous-loop rope mops that rotate between the vessel's hulls. Each rope mop is 12 inches in diameter and makes contact with the water over a distance of nearly half the vessel's length. The cutaway drawing in Figure 6 illustrates the approximate location of the mops between the hulls. Photos 32 and 33 show the rope mops at the stern of the ARCAT as they appear during operation. The roller assembly (or pulleys) at the rear of the boat are normally raised a few feet above the water and behind the collection "drip" pan so that there is ample space (and time) for water to drain back into the sea while leaving any recovered oil on the mops.

Since the mops are rotated at a speed to match the vessel's speed, the zero relative velocity (ZRV) between the mops and the oil/ice/water provides an excellent condition for oil transfer to the mops. As ice was observed passing between the vessel's hulls, the mops generally had sufficient slack to meander over and around the variety of ice contours encountered. The rope mop skimmers were operated in open water and in moderately heavy ice conditions (up to 7 oktas) throughout most of the 8 hours spent at sea.

Photo 32 also shows the position and relative size of the ARCAT's secondary recovery unit, a weir skimmer that can be lowered into position immediately aft of the rope roller assembly. As with the recovered oil from the rope mop skimmer, oil and water recovered with the weir skimmer is pumped directly to one of the ARCAT's 90-barrel waste-oil holding tanks.

The weir skimmer was used during the field demonstration to show how it would recover thick, viscous oil or burn residue in situations where the rop mops were less effective. The openings in the skimmer are large enough to accommodate a heavy layer of oil, and yet the unit could be raised and lowered quickly in response to occasional ice pieces, varying oil thickness, and sea conditions. Since the weir skimmer is normally used with very little forward motion, and because of the wind/wave protection offered by the vessel's hulls, the skimmer was observed to have good surface-keeping characteristics.

As a part of the recovery demonstrations, the ARCAT moved to and maintained position next to a simulated secondary oil-storage vessel (the tugboat Arctic Fox). Forty-five barrels of sea water were then transferred to the receiving vessel (in a closed loop to the ARCAT) to simulate the transfer of recovered oil from the ARCAT to a barge, bladder, or other storage unit. The entire transfer was completed in 16 minutes.

The ARCAT's heating system for its recovered oil storage tanks was also tested during the demonstration. It was shown that one of the systems was capable of raising 22 barrels of stored water from 73°F to 144°F in 3 hours and 20 minutes.

4.3.3 Support Systems

The 8-hour field demonstration involved the use of other support capabilities the ARCAT could conceivably provide during an actual oil spill. Photo 34, for example, shows the ARCAT with its dispersant spray booms extended at the bow of the vessel. Industry and agency observers watched the ARCAT's crew activate the dispersant system (without chemical dispersants), which provided a dispersed swath width well in excess of 50 feet. Spray nozzles between the hulls insure that dispersant will contact oil passing through the middle of the vessel as well.

Two fire monitors at the bow of the ARCAT (visible in Photos 31 and 34) were also demonstrated, by directing a powerful 4-inch stream of sea water (at 90 pounds per square inch) up to 190 feet from the vessel. The value of the fire monitors, other than for fighting fires, was shown to include: 1) the flushing of oil (hypothetical in this case) from ice surfaces and pockets so that the skimmers could then be used to recover the oil; 2) the diversion of oil on the surface toward the vessel's entry port for recovery; and 3) the concentrated and forceful application of a dispersant/sea-water mix on small, heavily oiled areas.

In summary, the folowing observations can be made:

- The ARCAT was demonstrated as an effective self-propelled vessel for delivering state-of-the-art skimming equipment to the scene of a spill even in the presence of up to 7 oktas decayed ice coverage during breakup.
- The ARCAT's maneuverability and speed are sufficient to enable the vessel to transit large distances quickly and safety under a broad range of environmental conditions.
- The ARCAT's oil recovery and support system appears to be in satisfactory operating condition for the kinds of potential oil-and-ice situations it may be expected to work in.

- During the 8-hour demonstration, the ARCAT's rope mop skimmers were operated in open water and in ice conditions up to 7 oktas decayed ice while experiencing no mechanical failures, no unexpected shutdowns, and no navigational or maneuvering difficulties.

- It was demonstrated that each of the ARCAT's two 90-barrrel recovered-oil storage tanks could be emptied in approximately 32 minutes. (Each tank has its own transfer pump, and both pumps can be operated simultaneously).

4.4 Task 4: Operation of Barges and Tugs in Broken Ice

Task 4 was conducted over an 8-day period beginning on July 12, 1983. During this period, industry and agency personnel observed and carefully documented the transport of two 2,150-horsepower tugs and 200-foot ice-breaking barge through varying degrees of ice cover between Prudhoe Bay and Barter Island. When these three vessels reached Barter Island, personnel from Crowley Maritime Corporation (owner/operator of the tugs and barge) then began to mount a major staging operation involving a total of 10 tugs and 15 barges, also owned by Crowley. During the last 2 days of this 8-day effort, the entire fleet moved back over the same route to Prudhoe Bay, a distance of over 100 nautical miles.

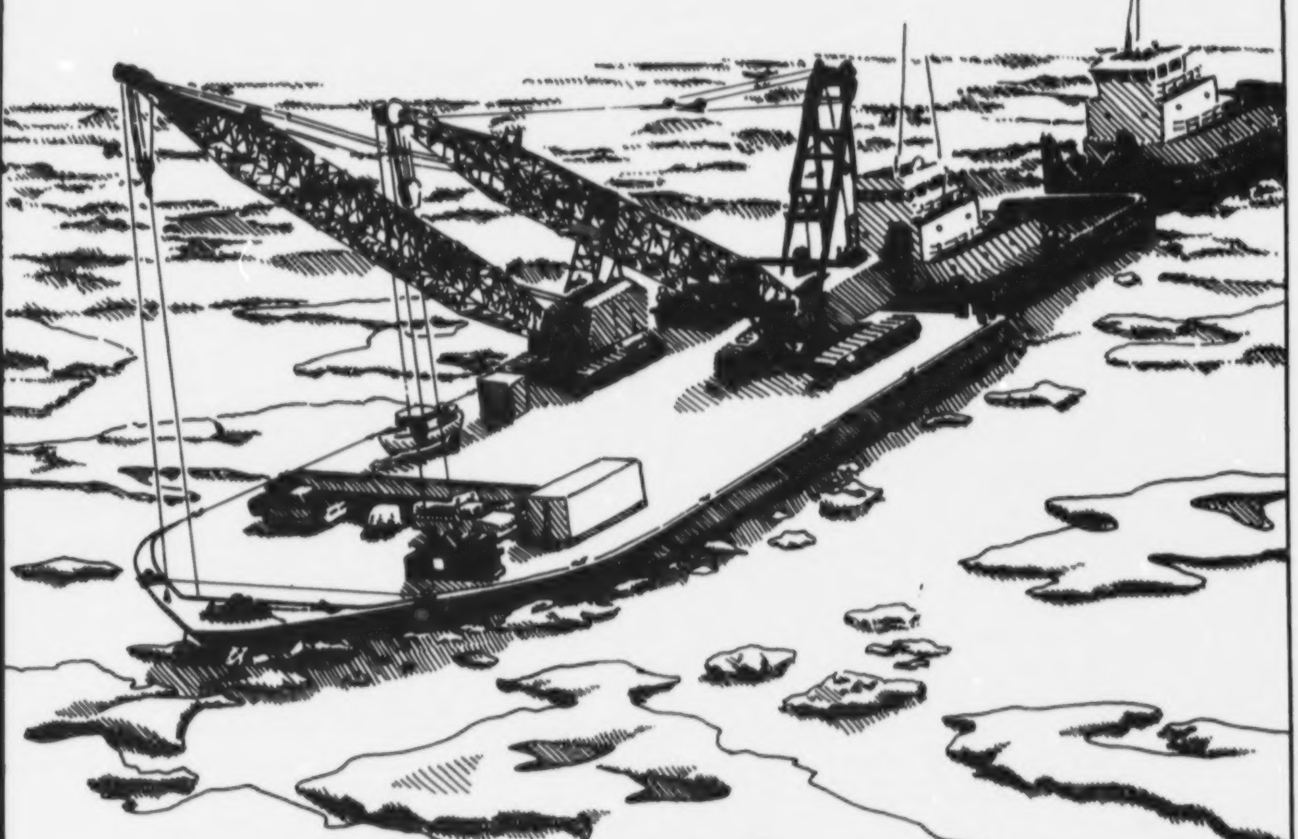
One industry representative traveled aboard one of the tugboats throughout the entire trip. His observations are described in Figures 7 and 8. In addition, videotapes and 35 mm still photography were used to document the sea/ice conditions along both legs of the trip. Industry and agency personnel made frequent overflights as the tugs and barges made their way between Prudhoe Bay and Barter Island and back again. Aerial coverage of these efforts included videotapes, 16 mmm movies, and 35 mm still photography.

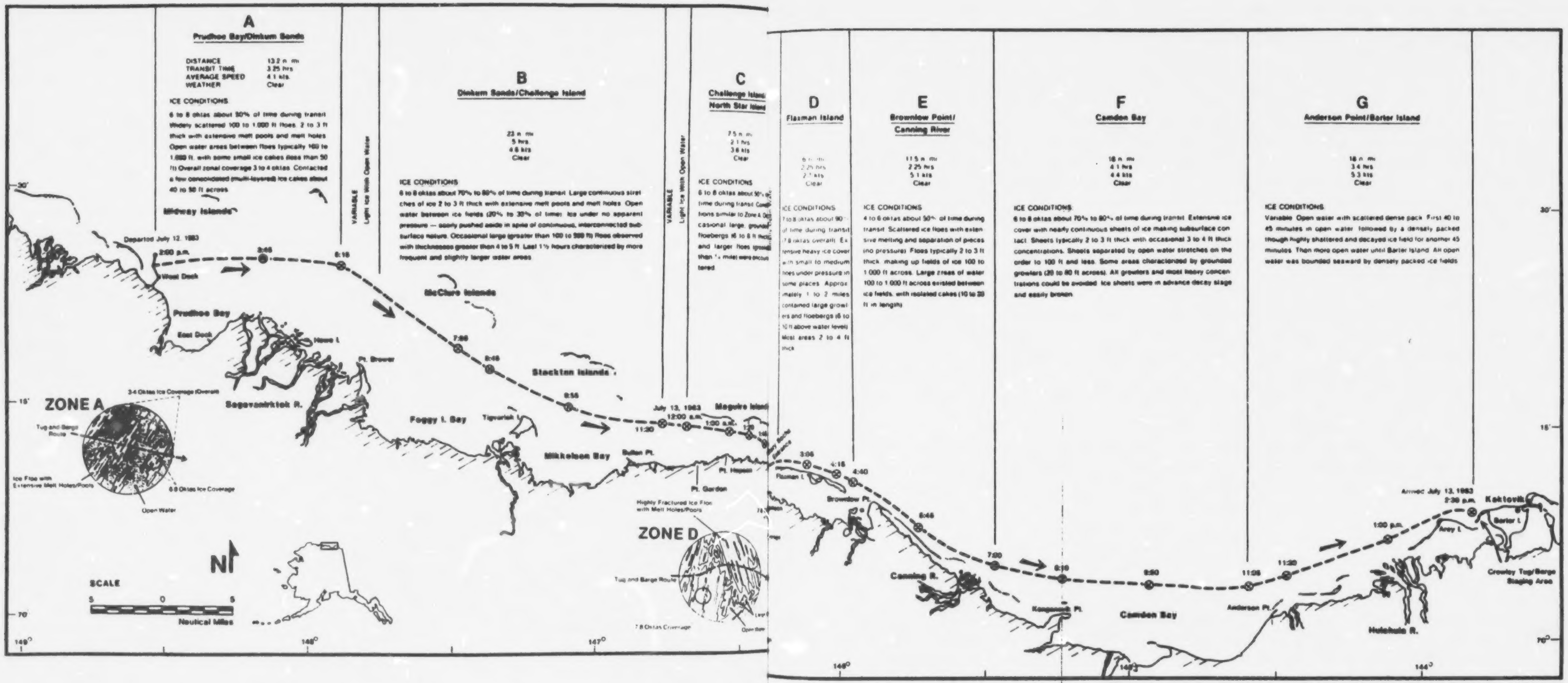
The objectives of this task were to witness, record and assess the experiences of Crowley Maritime Corporation while moving its tugs and barges through varying kinds and degrees of ice coverage during breakup in the Beaufort Sea. It was hoped that the trip might involve heavy broken-ice conditions (at least 5 to 6 oktas) over distances that would satisfy the State's demonstration requirements involving the utility of tugs and barges in broken ice. The ice conditions encountered provided ample opportunity to meet the objectives of Task 4.

Agency personnel were specifically interested in how Crowley's operations might demonstrate the logistical support capabilities of tugs and barges in response to a major offshore oil spill in the Arctic. It was recognized that additional information would be obtained from Kodiak Marine Transport's movement of its non-ice-breaking 200-foot SATCO 10 barge from Flaxman Island to Prudhoe Bay during the same ice conditions experienced by Crowley.

TASK 4

Operation of Barges and Tugs in Broken Ice




A
Prudhoe Bay/Dinkum Sands
DISTANCE 13.2 n. mi
TRANSIT TIME 3.25 hrs
AVERAGE SPEED 4.1 kts.
WEATHER Clear
B
Dinkum Sands/Challenge Island
23 n. mi
5 hrs.
4.6 kts
Clear
C
Challenge Islan
North Star Islan
7.5 n. mi
2.1 hrs
3.6 kts
Clear
D
Flaxman Island
6 n. mi
2.25 hrs
2.7 kts
Clear
E
Brownlow Point/
Canning River
11.5 n. mi
2.25 hrs
5.1 kts
Clear
F
Camden Bay
18 n. mi
4.1 hrs
4.4 kts
Clear
G
Anderson Point/Barter Island
18 n. mi
3.4 hrs
5.3 kts
Clear
VARIABLE
Light Ice With Open Water
Midway Islands
Departed July 12, 1983
2:00 p.m.
3:46
5:15
West Dock
Prudhoe Bay
East Dock
Heald Pt.
Pt. Brower
McClure Islands
7:00
8:46
Stockton Islands
9:55
ZONE A
3-4 Oktas Ice Coverage (Overall)
Tug and Barge Route
Ice Floe with Extensive Melt Holes/Pools
6-8 Oktas Ice Coverage
Open Water
Sagavanirktok R.
Foggy I. Bay
Tigvariak I.
Mikkelsen Bay
Bullen Pt.
Pt. Hopson
Pt. Gordon
July 13, 1983
12:00 a.m.
11:30
1:00 a.m.
Maguire Island
ZONE D
Highly Fractured Ice Floe with Melt Holes/Pools
Tug and Barge Route
7-8 Oktas Coverage
Open Water
SCALE
5 0 5
Nautical Miles
30'
15'
70°
149°
148°
147°
146°
145°
144°
3:05
4:15
4:40
Flaxman I.
Brownlow Pt.
5:46
7:00
8:10
9:50
11:05
11:20
Canning R.
Konganevik Pt.
Camden Bay
Anderson Pt.
Hulahula R.
1:00 p.m.
Arrived July 13, 1983
2:30 p.m.
Kaktovik
Barter I.
Arey I.
Crowley Tug/Barge Staging Area

A — ICE CONDITIONS

6 to 8 oktas about 50% of time during transit. Widely scattered 100 to 1,000 ft floes, 2 to 3 ft thick with extensive melt pools and melt holes. Open water areas between floes typically 100 to 1,000 ft, with some small ice cakes (less than 50 ft). Overall zonal coverage 3 to 4 oktas. Contacted a few consolidated (multi-layered) ice cakes about 40 to 50 ft across.

B — ICE CONDITIONS

6 to 8 oktas about 70% to 80% of time during transit. Large continuous stretches of ice 2 to 3 ft thick with extensive melt pools and melt holes. Open water between ice fields (20% to 30% of time). Ice under no apparent pressure — easily pushed aside in spite of continuous, interconnected subsurface nature. Occasional large (greater than 100 to 500 ft) floes observed with thicknesses greater than 4 to 5 ft. Last 1½ hours characterized by more frequent and slightly larger water areas.

C — ICE CONDITIONS

6 to 8 oktas about 50% of time during transit. Condi tions similar to Zone A. Oc casional large, ground floebergs (6 to 8 ft thic and larger floes (great than ¼ mile) were encoun tered.

D — ICE CONDITIONS

7 to 8 oktas about 90% of time during transit (7-8 oktas overall). Extensive heavy ice cover with small to medium floes under pressure in some places. Approximately 1 to 2 miles contained large growlers and floebergs (6 to 10 ft above water level). Most areas 2 to 4 ft thick.

E — ICE CONDITIONS

4 to 6 oktas about 50% of time during transit. Scattered ice floes with extensive melting and separation of pieces (no pressure). Floes typically 2 to 3 ft thick, making up fields of ice 100 to 1,000 ft across. Large areas of water 100 to 1,000 ft across existed between ice fields, with isolated cakes (10 to 20 ft in length).

F — ICE CONDITIONS

6 to 8 oktas about 70% to 80% of time during transit. Extensive ice cover with nearly continuous sheets of ice making subsurface contact. Sheets typically 2 to 3 ft thick with occasional 3 to 4 ft thick concentrations. Sheets separated by open water stretches on the order to 100 ft and less. Some areas characterized by grounded growlers (20 to 80 ft across). All growlers and most heavy concentrations could be avoided. Ice sheets were in advance decay stage and easily broken.

G — ICE CONDITIONS

Variable. Open water with scattered dense pack. First 40 to 45 minutes in open water, followed by a densely packed though highly shattered and decayed ice field for another 45 minutes. Then more open water until Barter Island. All open water was bounded seaward by densely packed ice fields.

Figure 7 Voyage of Tug-and-Barge Train from Prudhoe Bay to Barter Island (Task 4)
(Approximately 104 nautical miles in 24.5 hours; average speed 4¼ knots)

4.4.1 Observations: Prudhoe Bay to Barter Island

Figure 7 contains information summarizing the progress and the weather and ice conditions experienced by Crowley's ice breaker the Arctic Endeavor and its tugs, the Pt. Thompson and Pt. Barrow, while en route to Barter Island. The route of the Endeavor is presented with postiion/time marks as recorded during the trip. In addition, zones have been identified within which ice conditions remained relatively constant.

As indicated on the chart, the Arctic Endeavor encountered extensive areas of heavy ice cover (6 to 8 oktas) with intermittent open-water stretches in Zones A, B, C, D and F. With only a little less coverage in Zone E, the Endeavor was exposed to frequent, and in some cases nearly continuous encounters with ice floes typically 2 to 3 feet thick (Photos 36, 37 and 38). Most floes were hundreds of feet in length and in advance stages of melt. Melt pools and holes had grown to between 20% and 40% of each floe's surface area.

The average speed of the Endeavor and its tugs pushing in tandem is provided in Figure 7 for each of the zones. In most of the heavy ice concentrations, the tug-and-barge combination was capable of maintaining an average speed of 3½ to 4½ kts. Zone D, off Flaxman Island, however, contained a nearly continuous field of unusually thick ice under some pressure. The compact pack ice contained many floebergs and growlers which forced the Endeavor and its tugs to slow down while avoiding the largest pieces. Even with a few stops to back up and break through some 3 to 4-foot-thick floes, the Endeavor managed to average 2.7 knots in Zone D.

Zones E and G had considerably more open water so that average speeds in excess of 5 knots were possible. The Endeavor had plenty of room to maneuver around ice floes in these regions, and rarely had to slow down.

The entire trip was completed between Prudhoe Bay and Barter Island in 24½ hours, over a route that covered about 104 nautical miles. An average speed of 4½ knots was therefore achieved through extensive regions of close pack-ice and in many cases, in nearshore shallow waters. The Arctic Endeavor and its two 2,150-horsepower tugs pushing in tandem completed the trip with no unusual equipment failures or delays caused by ice it could not handle.

While moving past Flaxman Island (Zone D), the Endeavor passed Kodiak's SATCO 10 barge en route from Flaxman Island to Prudhoe Bay. The 200-foot SATCO 10 BARGE (Photo 39) has a conventional hull (i.e., non-ice-breaking); however, by carefully maneuvering the barge with two tugs pushing in tandem, it was moved through the same basic ice conditions encountered by the Endeavor in Zones, A, B, C, and D. By moving the SATCO 10 slowly and pushing over or around the larger ice pieces, Kodiak was able to complete the 55-nautical-mile trip in about 26½ hours, averaging better than 2 knots.

4.4.2 Observations: Barter Island to Prudhoe Bay

At Barter Island a total of 10 tugs and 15 barges were prepared for the trip back to Prudhoe Bay. Most of the tugs had to be lifted from the barges and set in the water since the fleet had wintered at Barter Island. The complete staging operation, conducted in moving ice with strong currents, was representative of the kind of logistical support operations that could be required and carried out in conjunction with an oil spill. The size and number of tugs and barges present could have easily supported the berthing, messing and work-related needs of several hundred field personnel.

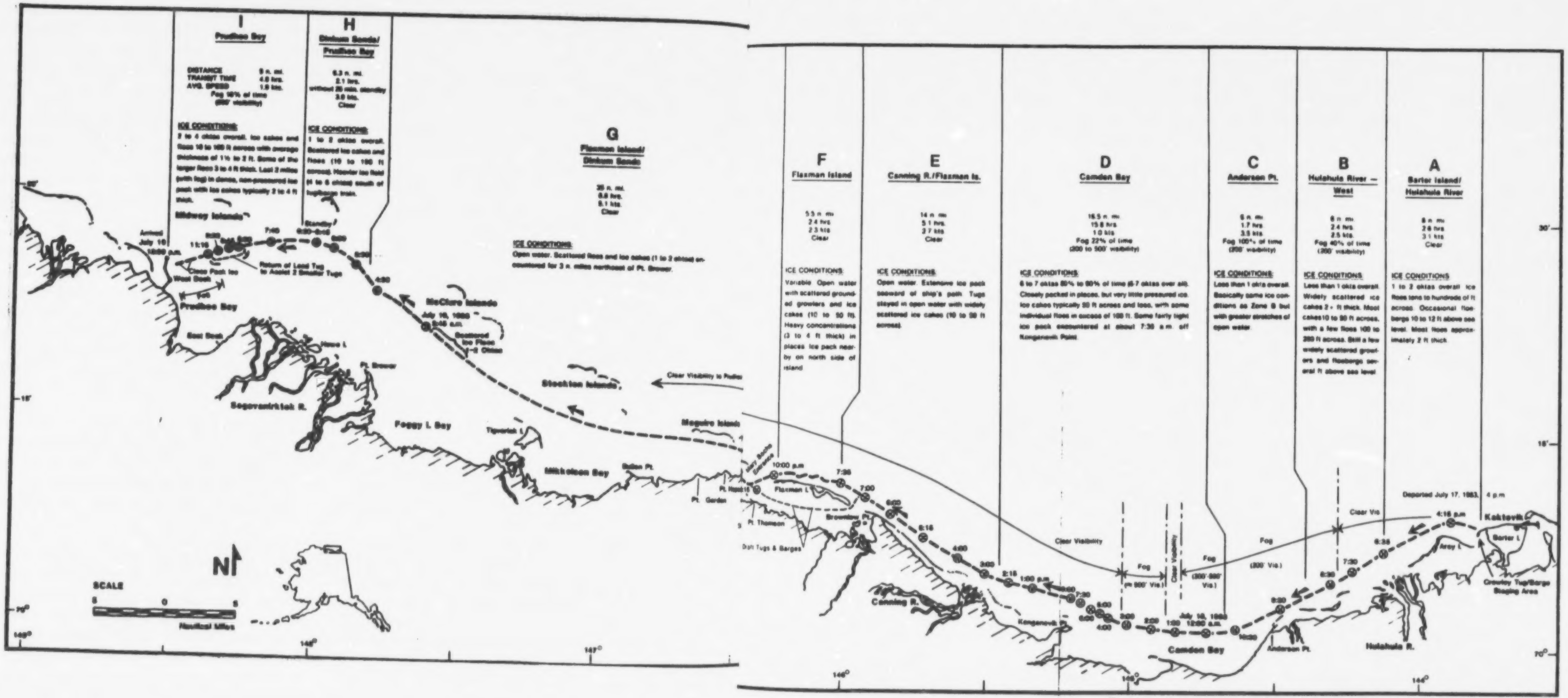
Shortly after departure on July 17, 1983, all tugs and barges had moved into a tight formation for the trip back to Prudhoe Bay (Photo 40). As shown in Figure 8, the tug-and-barge train entered a fairly dense fog bank just a few hours out of Barter Island. Traveling through varying degrees of poor visibility and ice coverage, the train moved along at between 1 and 3.5 knots, thus insuring that all vessels remained within sight of their neighboring vessel(s).

As in the trip to Barter Island, all ice conditions encountered by the fleet were handled without mishap. Some minor tow-line adjustments and mechanical repairs typical of any marine operation had to be completed along the way. These corrections and repairs were made wihout any significant delay. Even under visibility conditions of a few hundred feet, the train was able to reach Flaxman Island the following evening, a distance of about 50 nautical miles.

At this point, the shallow-draft tugs and barges broke off (Photo 41) and moved into the very shallow waters (5 to 6 feet in places) south of Flaxman Island. The deeper-draft vessels continued on the north side of Flaxman Island and encountered remnants of the same massive floes and grounded hummocks that were passed through on the way to Barter Island.

As the routes of all vessels rejoined in Mary Sachs Entrance, clear weather and open water permitted the tugs and barges to move independently of each other. Most tug-and-barge combinations were able to maintain 5-knot speeds throughout Zone G, after which the vessels rendezvoused and moved slowly through Zone H while awaiting ice reports for the last leg to West Dock.

During the last few miles approaching West Dock, the tugs and barges had to operate under some of the most difficult conditons of the entire trip. Shallow water depths, dense fog (200-foot visibility or less), and close pack ice required that each vessel maintain a safe, accurate position relative to the other vessels, The trip through Zone I included a shift of the Pt. Thompson from a pulling mode to a pushing mode wih its conventional (non-ice breaking) barge in drifting, open pack ice; a return of the Pt. Thompson and barge to assist two smaller tugs in making better speed through the ice; and the safe positioning and anchoring of 10 tugs and 15 barges in a small area off West Dock using radar and lookouts with radio communications on the barges.



I
Prudhoe Bay

DISTANCE 9 n. mi.
TRANSIT TIME 4.8 hrs.
AVG. SPEED 1.9 kts.
Fog 16% of time
(200' visibility)

ICE CONDITIONS:
2 to 4 oktas overall. Ice cakes and floes 10 to 100 ft across with average thickness of 1½ to 2 ft. Some of the larger floes 3 to 4 ft thick. Last 2 miles (with fog) in dense, non-pressured ice pack with ice cakes typically 2 to 4 ft thick.

H
Dinkum Sands/ Prudhoe Bay

6.3 n. mi.
2.1 hrs.
without 25 min. standby
3.0 kts.
Clear

ICE CONDITIONS:
1 to 2 oktas overall. Scattered ice cakes and floes (10 to 100 ft across). Heavier ice field (4 to 5 oktas) south of tug/barge train.

G
Flaxman Island/ Dinkum Sands

35 n. mi.
6.8 hrs.
5.1 kts.
Clear

ICE CONDITIONS:
Open water. Scattered floes and ice cakes (1 to 2 oktas) encountered for 3 n. miles northeast of Pt. Brower.

F
Flaxman Island

5.5 n. mi
2.4 hrs.
2.3 kts
Clear

ICE CONDITIONS:
Variable. Open water with scattered grounded growlers and ice cakes (10 to 50 ft). Heavy concentrations (3 to 4 ft thick) in places. Ice pack nearby on north side of island.

E
Canning R./Flaxman Is.

14 n. mi
5.1 hrs.
2.7 kts
Clear

ICE CONDITIONS:
Open water. Extensive ice pack seaward of ship's path. Tugs stayed in open water with widely scattered ice cakes (10 to 20 ft across).

D
Camden Bay

16.5 n. mi.
15.8 hrs
1.0 kts
Fog 22% of time
(200 to 500' visibility)

ICE CONDITIONS:
6 to 7 oktas 80% to 90% of time (6-7 oktas over all). Closely packed in places, but very little pressured ice. Ice cakes typically 20 ft across and less, with some individual floes in excess of 100 ft. Some fairly tight ice pack encountered at about 7:30 a.m. off Kongenevik Point.

C
Anderson Pt.

6 n. mi.
1.7 hrs
3.5 kts
Fog 100% of time
(200' visibility)

ICE CONDITIONS:
Less than 1 okta overall. Basically same ice conditions as Zone B but with greater stretches of open water.

B
Hulahula River — West

6 n. mi.
2.4 hrs.
2.5 kts.
Fog 40% of time
(200' visibility)

ICE CONDITIONS:
Less than 1 okta overall. Widely scattered ice cakes 2+ ft thick. Most cakes10 to 20 ft across, with a few floes 100 to 200 ft across. Still a few widely scattered growlers and floebergs several ft above sea level.

A
Barter Island/ Hulahula River

8 n. mi.
2.6 hrs
3.1 kts
Clear

ICE CONDITIONS:
1 to 2 oktas overall. Ice floes tens to hundreds of ft across. Occasional floebergs 10 to 12 ft above sea level. Most floes approximately 2 ft thick.

Arrived July 10 10:00 p.m.
11:15
Midway Islands
7:40
Standby 6:20-6:45
Close Pack Ice
West Dock
Return of Lead Tug to Assist 2 Smaller Tugs
4:30
Prudhoe Bay
East Dock
Howe I.
Pt. Brower
McClure Islands
July 10, 1983 2:45 a.m.
Scattered Ice Floes 1-2 Oktas
Sagavanirktok R.
Foggy I. Bay
Tigvariak I.
Stockton Islands
Clear Visibility to Prudhoe
Maguire Islands
Mikkelsen Bay
Bullen Pt.
Pt. Hopson
Pt. Gordon
Pt. Thomson
Dinkum Sands Entrance
10:00 p.m
Flaxman I.
Brownlow Pt.
Drift Tugs & Barges
7:35
7:00
6:00
5:15
4:00
3:00
2:15
1:00 p.m.
7:30
6:00
5:00
4:00
Canning R.
Kongenevik Pt.
Clear Visibility
Fog
(± 500' Vis.)
Clear Visibility
Fog
(200'-500' Vis.)
Fog
(200' Vis.)
Clear Vis
3:00
2:00
1:00
July 16, 1983 12:00 a.m.
10:30
Camden Bay
Anderson Pt.
9:30
8:30
7:30
6:35
4:15 p.m
Departed July 17, 1983, 4 p.m
Kaktovik
Barter I.
Arey L.
Crowley Tug/Barge Staging Area
Hulahula R.
N
SCALE
5 0 5
Nautical Miles
15'
30'
70°
149°
148°
147°
146°
145°
144°

Figure 8 Voyage of Tug-and-Barge Train from Barter Island to Prudhoe Bay (Task 4)
(Approximately 108 nautical miles in 44 hours, average speed 2.4 knots)

The entire trip took a little less than 2 days to complete, averaging 2.4 knots over the estimated return route of about 106 nautical miles.

In summary, the following statements can be made regarding the tug-and-barge operations in Task 4:

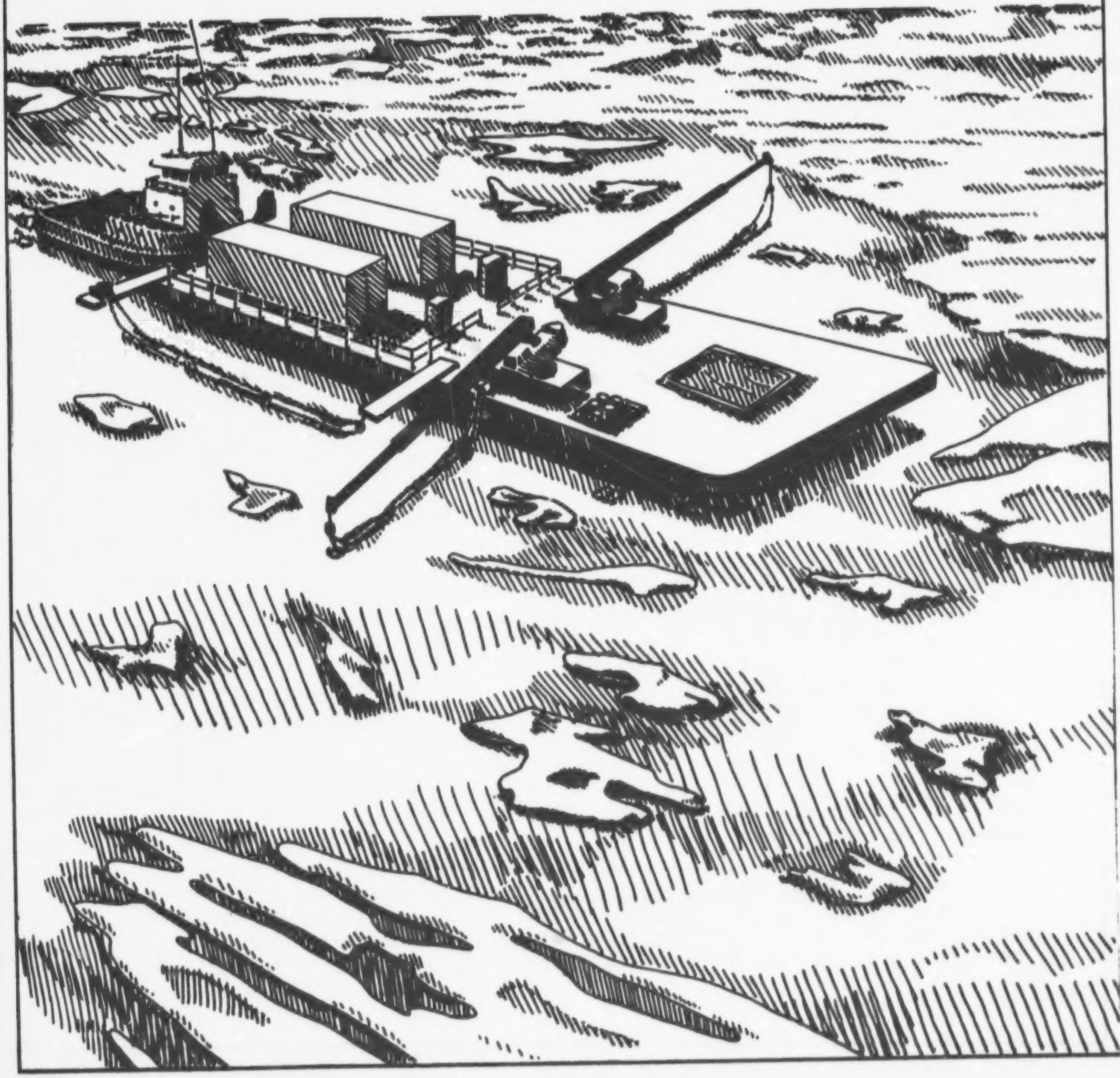
- Tugboats operating with specially designed ice-breaking barges can provide an effective means of moving heavy equipment over great distances in up to 7 to 8 oktas ice coverage with speeds of 2 to 5 knots during breakup in the Arctic. (Based on sea trials in the fall of 1982, the Arctic Endeavor also shows excellent promise of breaking new sea ice during freeze-up at thicknesses in excess of 1 foot.)
- Operations can be carried out during early breakup using conventional (non-ice-breaking) tugs and barges in close pack ice (6 to 7 oktas) when the ice is in an advanced stage of melt and is non-pressured.
- Tugs and barges offer an effective means of carrying out massive offshore logistical support activities in conjunction with oil spill response efforts near Prudhoe Bay or in remote areas of the Arctic.
- Tugs and barges can be selected to operate in very shallow waters and if necessary, can be deliberately grounded or beached to support shoreline or nearshore cleanup activities.
- Tugboats and barges of a wide variety of sizes, shapes, horsepower, and capabilities are available for operations in the Beaufort Sea.
- The speed and maneuverability of tugs working with barges are sufficient even under adverse weather and ice conditions in the Arctic to support a broad range of spill response needs. (This observation is strengthened by the results of Task 5 in the following section.)

4.5 Task 5: Operation of Rope Mops from a Barge in Broken Ice and Open Water

Task 5 was carried out on July 16 and 17, 1983. Kodiak Marine Transport's tugboat, the Arctic Fox, and its 200-foot by 60-foot barge, the SATCO 10, were used to demonstrate the feasibility of operating rope mop skimmers from the side of a barge in broken-ice conditions. Working in waters between 2 and 5 nautical miles northwest of West Dock, the 1,750-horsepower Arctic Fox and the SATCO 10 provided a base of operations for the mobilization, deployment, operation and demobilization of three rope mop skimmers. The skimmers were CSI Z-14E and MW 62 rope mop skimmers provided by ABSORB and operated by industry representatives and their contractor, Alaska Offshore Inc. Figure 9 illustrates the layout of the skimmers and all support facilities and equipment on board the barge.

TASK 5

Operation of Rope Mops from a Barge In Broken Ice and Open Water



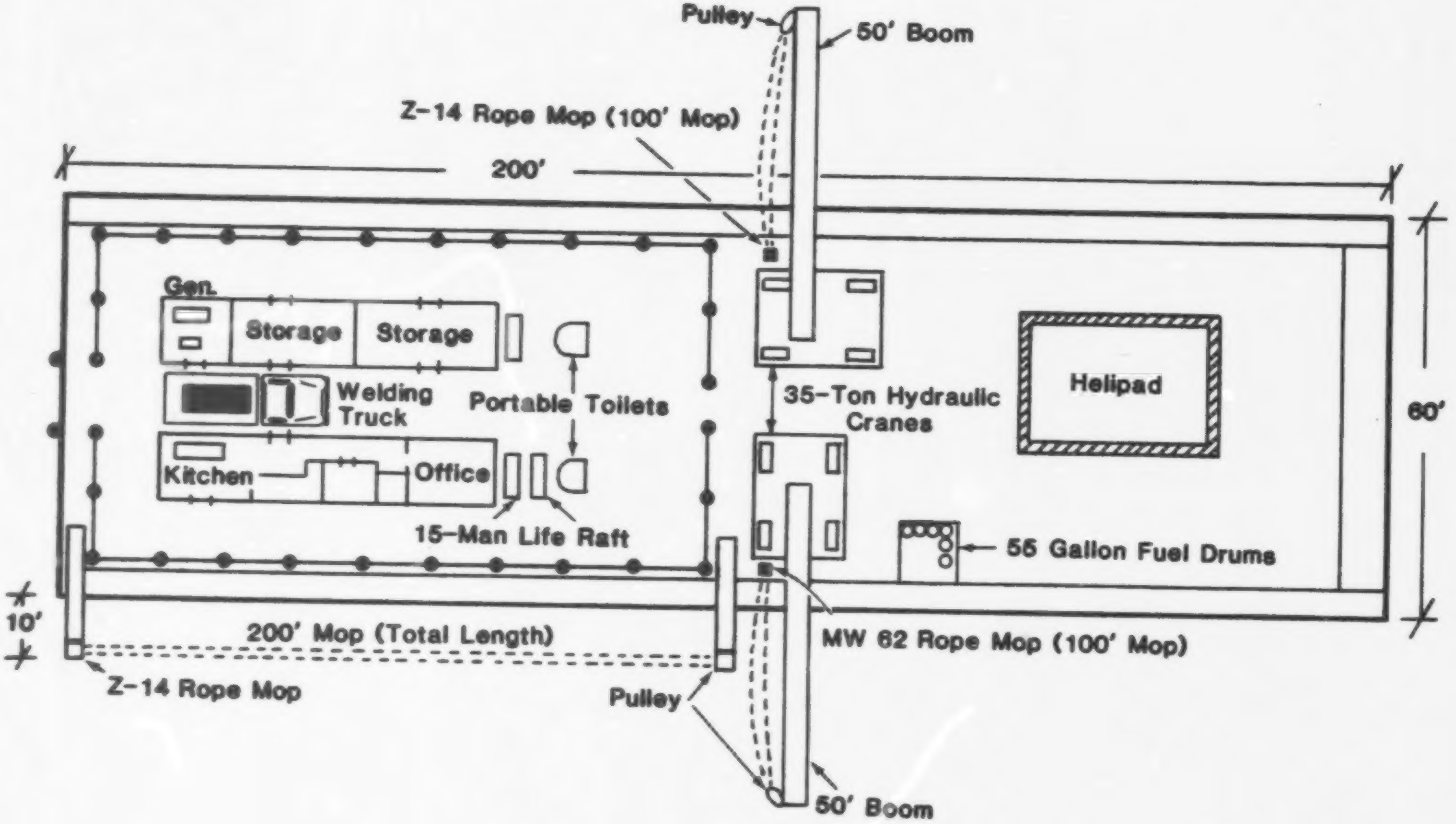

Pulley
50' Boom
Z-14 Rope Mop (100' Mop)
200'
Gen.
Storage
Storage
Welding
Truck
Portable Toilets
Kitchen
Office
15-Man Life Raft
35-Ton Hydraulic
Cranes
Helipad
60'
55 Gallon Fuel Drums
10'
200' Mop (Total Length)
MW 62 Rope Mop (100' Mop)
Z-14 Rope Mop
Pulley
50' Boom

Figure 9 Plan of Barge with Rope Mop Skimmers (Task 5)

Industry and agency personnel observed and recorded the simulated oil recovery operations with videotapes, 16 mm movies, and still photography. The time that each skimmer was operated in a favorable recovery condition was noted, along with the ice conditions, weather, and general performance of each unit. Agency representatives wanted to evaluate the effectiveness of barge-mounted rope mop skimmers in 2 to 4 oktas over an 8-hour period. Part of the objectives was to assess the interaction of the mops with moving and stationary ice, the need to reposition the mops for proper oil/water exposure, the durability of mops and wringer assemblies, and any down-time required for repairs. One final concern of agency personnel was the practicality of moving barges (with skimmers) into regions of high ice concentrations and the ability to then maintain a proper orientation for picking up oil.

Preparations

Approximately 2 days were taken to outfit the SATCO 10 barge with the oil spill response and support facilities needed to carry out Task 5. In an actual oil spill emergency, of course, this time could be reduced considerably by working around the clock with more people. Two steel walkways were cantilevered out from the barge 100 feet apart to support one of the rope mop skimmers and its return pulley. Two 35-ton, hydraulic, telescoping cranes were also positioned amidships on the barge to support the pulleys for two additional rope mop skimmers.

The barge was outfitted with generators, fuel, a helipad and other life support facilities that could actually be used in the event of a spill. Fence posts and safety lines were secured to the deck and to the extended walkways to provide safe working conditions for observers and for the equipment operators. In addition, specially designed pulley mounts and brackets were fabricated in advance to meet the variety of rope mop deployment schemes that might be used during the demonstration.

Results

Shortly before noon on July 16, the tug-and-barge combination departed West Dock and transited ice coverages between 2 and 8 oktas on its way to the first simulated recovery site (Photo 42). Weather conditions upon departure included good visibility, with air temperatures in the low 40's (°F) and calm wind/sea conditions. By mid-afternoon, the barge had already been positioned in a variety of configurations to demonstrate the tugboat's ability to maneuver the barge up to and against the edge of a field of close pack-ice. The three skimming units were started at different times, and were all properly in position and working successfully by about 6:00 p.m.

The MW 62 rope mop, suspended at right angles to the barge by one of the cranes, experienced no difficulties in moving over and between ice cakes in 2 to 7 oktas concentration. During its first hour of operation, however, the return pulley had to be lifted from the water's surface repeatedly to avoid damage from the moving ice. In one situation, its mop became entangled on a piece of ice, and the mop had to be cut and retied. Approximately a 5-minute delay was experienced in retying the mop. Immediate modifications were then made to shorten the length of the mop from 150 to 100 feet and to increase the height of the pulley above the water. As a result, the crane operator was able to maintain good control over the rope mop under varying ice conditions.

With 100 feet of rope mop deployed on each of the crane-supported mops off each side of the barge, approximately 30% to as much as 75% of the mop was typically in contact with water during the operations in 2 to 7 oktas coverage (Photo 43). The mops were also capable of maintaining their usual rotational speed of 1 foot per second throughout the demonstration.

The Z-14E rope mop with 200 feet of mop strung along the side of the barge proved to be an effective means of exposing the rope mop to heavy ice concentrations with minimal chance of snagging. In this mode, the barge could be positioned so that its side could be used in directing or concentrating the flow of oil (simulated) to enhance recovery. Steps did have to be taken to move the rope mop farther out from its initial position in order to avoid the occasional suction of the rope mop beneath the barge's hull. In addition, the tail pulley was changed from a floating horizontal configuration to a suspended vertical one. Once the pulley was moved, the rope mop was capable of configuring itself to the changing ice conditions as necessary (Photo 44).

By approximately 1:20 a.m. on July 17 (dense fog having closed in around 5:00 p.m. on July 16), agency and industry representatives agreed that the skimming operations had fulfilled the demonstration requirements. Sufficiently varying ice conditions had been encountered to meet their observational requirements. During the 8-hour demonstration, the three rope mop skimmers had accumulated a combined skimming time of nearly 17 hours. Time not devoted to skimming was spent primarily in transit. The majority of the skimming time and the transit back to dock was carried out in dense fog with 200-foot visibility or less. Throughout Task 5, there were no mechanical failures of the rope mops.

In summary, Task 5 helped support the industry's belief that:

- Tugs and barges represent one of the most effective means of supporting offshore and nearshore oil spill cleanup operations even in remote locations of the Arctic. Barges provide a mobile, stable platform for the storage of recovered oil, spill cleanup equipment, small boats, vehicles, shelters, etc. Deck space can also be provided for helicopter support.

- Tugboats can meaneuver conventional barges through arctic breakup conditions involving as much as 8 oktas of decaying ice, while providing station-keeping capabilities for skimming operations in moving broken ice.

- Rope mop skimmers can be deployed effectively from barges in heavy pack ice (up to 7 oktas), in lesser concentrations of stationary or moving ice (typically 1 knot or less), and along the edges of large floes or fields of dense pack-ice.

- Even with visibility reduced to 200 feet or less due to dense fog, the entire operation was conducted safely and with no mechanical failures of the skimming equipment. In addition, there were no signs of icing on the rope mops or the wringer assemblies.
- Both small (Z-14E) and large (MW 62) rope mops worked effectively from the side of the barge.

4.6 Task 6: Boom Deployment in Moving Broken Ice

Task 6 during the Tier 2 field demonstration program involved the offshore deployment, maintenance, and recovery of Shell's fire containment boom. More than 500 feet of boom (as modified during Task 2) were fabricated at Prudhoe Bay for testing in two modes of use. The first, Test 1, involved the positioning of the entire length in a U-configuration in the lee of Tern Island with moving broken ice (4 to 6 oktas). The second, Test 2, involved the aerial deployment of 240 feet of the fire containment boom into drifting ice (approximately 3 oktas) and the subsequent behavior of the boom while it drifted freely with the ice for a minimum of 24 hours. Figure 10 indicates the approximate locations of the two tests.

For Test 1, agency personnel requested that a 30-foot section of boom used in earlier burn tests be deployed as part of the demonstration. Therefore, Test 1 included 16 new sections of fire containment boom (as illustrated in Figure 5, Task 2) and a 30-foot used section, for a total of 510 feet.

The objectives of Task 6 were aimed at the logistical aspects of working with the fire containment boom in offshore, ice-infested waters. Concerns expressed by agency personnel during the early planning phases of Tier 2 involved the use of booms in general during ice conditions. However, since the industry's response plans frequently included the burning of any contained oil, government representatives asked that the booming operations include the use of fire containment boom. During these booming activities, careful consideration was to be given to the practicality of use in each mode; to safety factors and accessibility in the presence of ice; and to the survivability of the boom during all handling, transport, and simulated containment phases.

As in the previous tasks, all operations were once again documented thoroughly using videotapes, 16 mm movies, and 35 mm still photography.

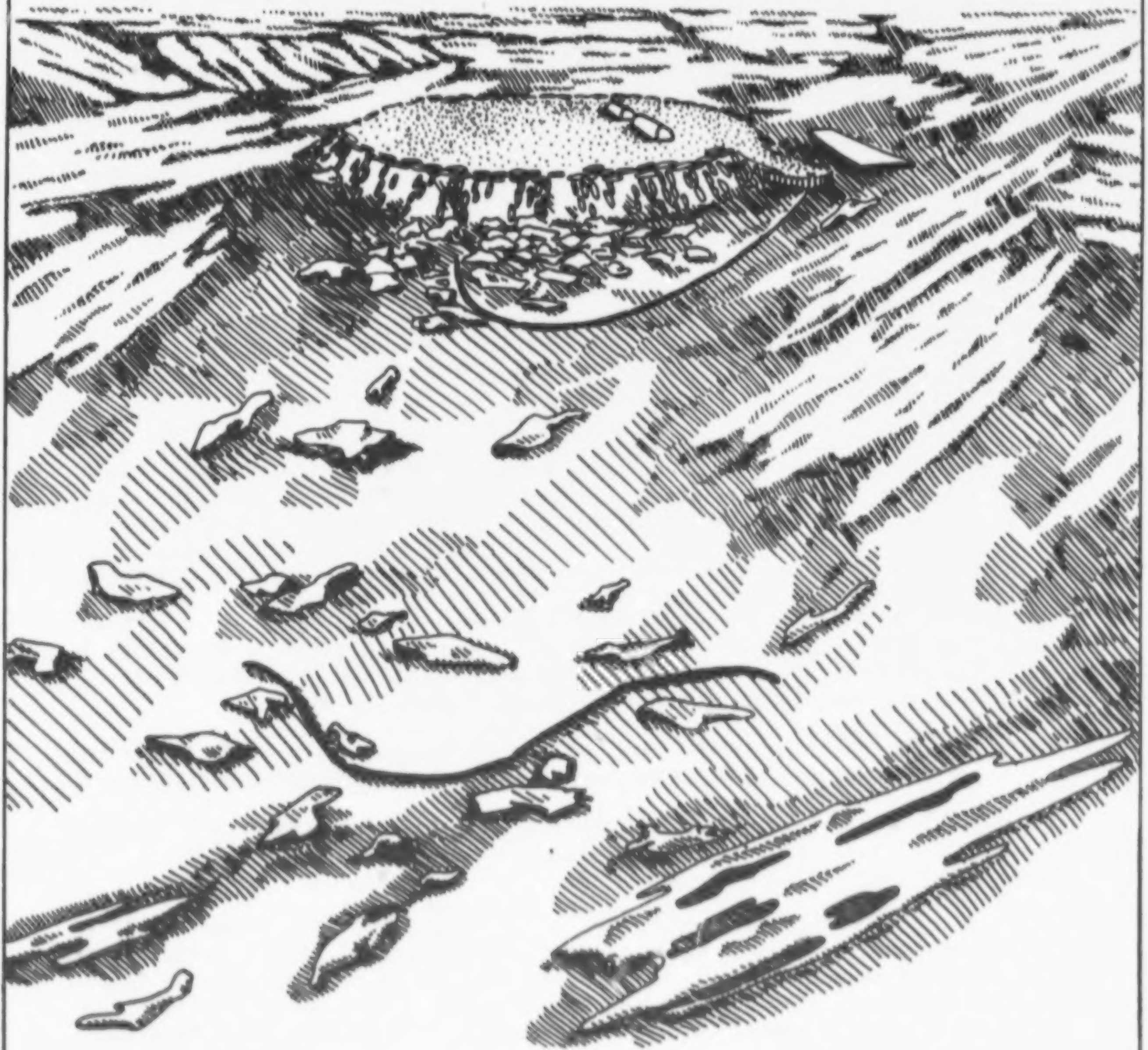
4.6.1 Test 1: U-Configuration Adjacent to Island (Anchored)

Preparations and Procedures

Before the field operations were conducted at Tern Island, Shell's fire containment boom had been fabricated in one of Sohio's buildings at East Dock, with about 34 hours being required to complete the 510 feet of boom. An estimated construction time of 2 hours per 30-foot section (with modifications) is based on three men working with small hand tools only.

TASK 6

Boom Deployment in Moving Broken Ice



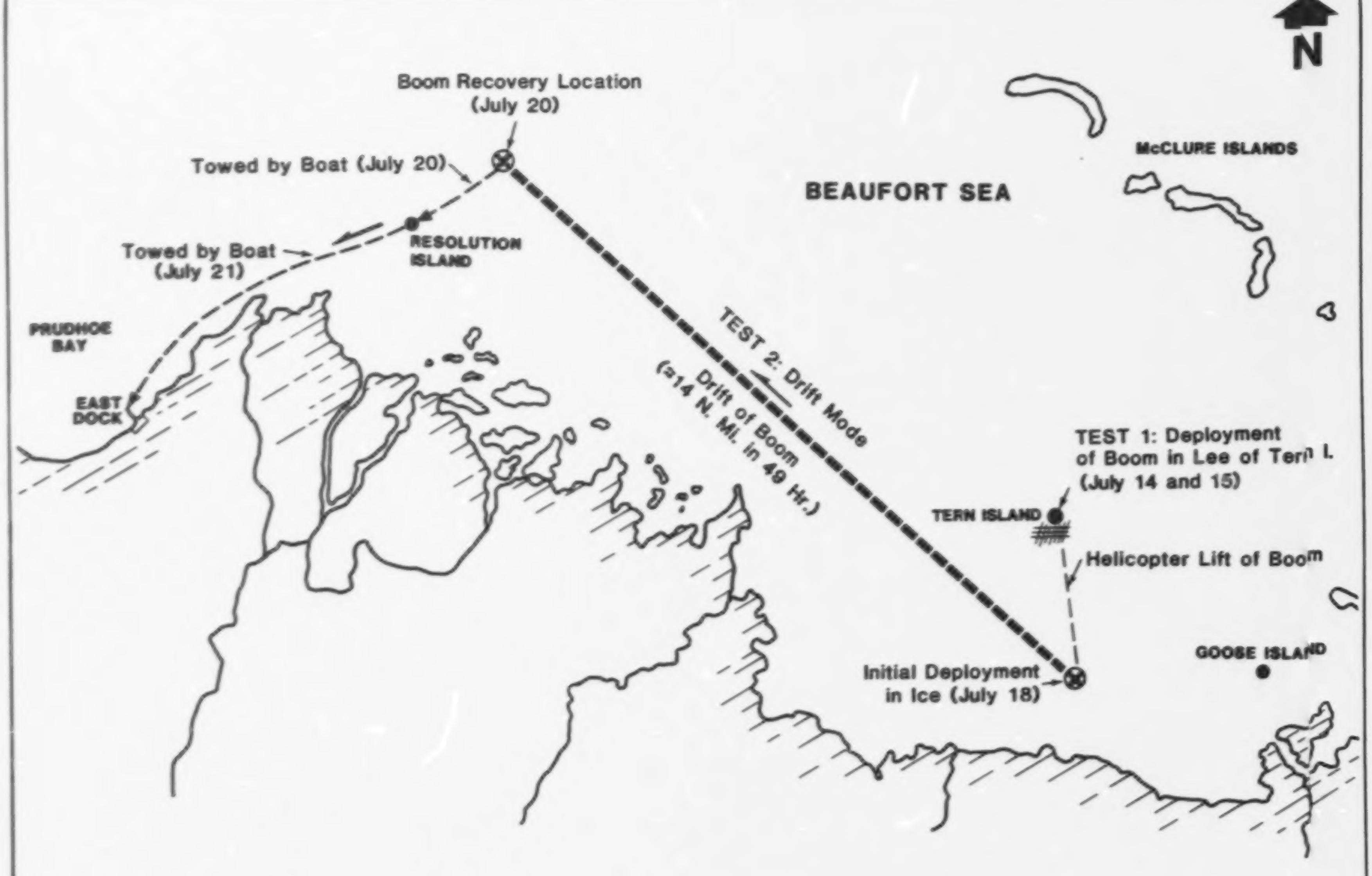

N
Boom Recovery Location
(July 20)
Towed by Boat (July 20)
RESOLUTION ISLAND
Towed by Boat
(July 21)
PRUDHOE BAY
EAST DOCK
BEAUFORT SEA
McCLURE ISLANDS
TEST 2: Drift Mode
Drift of Boom
(≈14 N. Mi. in 49 Hr.)
TEST 1: Deployment
of Boom in Lee of Tern I.
(July 14 and 15)
TERN ISLAND
Helicopter Lift of Boom
GOOSE ISLAND
Initial Deployment
in Ice (July 18)

Figure 10 Location Map: Task 6 Boom Deployment Sites

In addition, two 40-foot by 20-foot fabric shelters (Quonset-type) were erected on the island, emergency life-support equipment was stockpiled, and radiotelephone equipment was installed through Shell's Prudhoe Bay radio net. Small boats, motors, anchors, fuel, and other support equipment were brought in as well.

During the weeks preceding the demonstration, reconnaissance flights with State personnel were carried out routinely to observe the breakup process and to determine when it would be desirable to begin the exercise. On the morning of July 14, ice conditions were deemed to be sufficient to meet the requirements for the boom deployment task. Two men working from a 14-foot aluminum boat with a 15-horsepower motor easily pulled the boom into the water, while six men onshore lifted and guided the boom over the edge of the dock. By approximately 5:00 p.m., all sections of boom, including the burn-test section, had been flown to the island and positioned in the lee formed as ice concentrations in the 4 to 7 okta range approached and passed around the island (Photo 45).

Results

During the first 15 to 16 hours of exposure, the 510 feet of boom were monitored closely as light winds kept the south and southwestern sides of the island relatively free of ice. The boom, which was anchored in position between the dock and the shoreline, maintained a fairly constant configuration as ice moved by making very little contact with the boom (Photo 46).

Early that morning, however ice began to drift in from the west. The boom was then moved to the east side of the island. By mid-morning, ice (approximately 6 oktas) began to move in and rub against the boom. By noon, when the lee of the island had once again formed on the south side, another relocation of the boom was necessary. During the remainder of the time the boom was in the water, ice cakes and floes continued to contact the boom, moving past it at about 1/3 knot.

With more than 24 hours of exposure, the boom was pulled in at 5:00 p.m. on July 15 and set onshore for inspection. There appeared to be no loss of flotation prior to recovering the boom, and examination revealed no signs of damage from the ice or from handling the boom during deployment and recovery.

4.6.2 Test 2: Deployment of Boom in Drifting Ice

Preparations and Procedures

For Test 2, 240 feet of fire containment boom were taken from the boom used in Test 1 at Tern Island. Two full-scale trial deployments with the boom were conducted at East Dock to insure that the helicopter pilots were familiar with the boom's response characteristics and to determine the optimum speed for moving and setting a long section of boom.

Prior to deployment, the top side of the boom was painted with alternating orange squares and dots to facilitate locating and photographing the boom during aerial surveys. The boom was also equipped with a radio beacon to aid in locating the boom should visibility be poor.

On the day of the demonstration (July 18, 1983), industry and agency personnel gathered at Tern Island for the pickup of the boom with a Bell 212 helicopter. A remotely activated release hook was used at the end of a sling cable. Two men on the island attached one end of the boom to the hook. Communications were maintained between the island and the helicopter with a hand-held air-to-ground radio below.

As the wet boom was lifted from the water, its initial weight was in excess of 3,000 pounds (typically between 12 and 13 pounds per foot). After losing its excess water, the boom's overall weight then dropped about 500 pounds to between 10 and 11 pounds per foot (approximately twice its dry weight). The boom was then flown about 3 miles south while industry and agency personnel watched from three other helicopters in the area (Photo 47).

At about 3:20 p.m. on the July 18, the boom was set down in 3 oktas of ice coverage. With the wind at 5 knots from the east, observers watched the boom for an hour as it began to slowly drift toward the west (Photo 48). A second aerial survey was conducted a few hours following the boom's release.

Two days were allowed to pass before a serious attempt was made to locate the boom visually and with the radio beacon locator. The boom was found about 7:30 p.m. on July 20 and towed by boat to Sohio's Resolution Island, where it was anchored until it was moved to East Dock on July 21.

Results

During the pickup, transport and deployment of the boom, the Bell 212 experienced no difficulty in lifting and controlling the boom. A comfortable, safe speed without fish-tailing and without excessive angle on the boom was found to be between 30 and 45 knots.

While the helicopter pilot had no difficulty spotting the boom and releasing it precisely where he wanted it, it was difficult to keep the boom from developing a twist while it was being set. Two such twists were observed during the deployment of the boom. The boom could provide an effective barrier (with or without the benefit of its skirt) to the movement of oil drifting in and slightly faster than the ice.

The boom had drifted in moving broken ice approximately 14 nautical miles to the northwest in the two days it was in the water, for an average drift rate of 1/3 knot. After being picked up by boat and towed to Resolution Island, the boom was once again left in the water overnight until it could be picked up the next day and towed to East Dock. With the end of the boom pulled up onto the towing boat to prevent submergence while in tow, the boom could be moved comfortably at about 2½ knots.

Upon recovery at East Dock, the boom revealed no signs of wear due to exposure to the ice or from the towing operation. Prior to the boom's removal, it was noted that the boom had no significant loss in freeboard.

In summary, the results of both tests in Task 6 suggest that:

- The Shell fire containment boom as presently configured is capable of withstanding the forces encountered during normal deployment operations from shore and during airlift operations by helicopter.
- The fire containment boom can be easily constructed on site.
- Even after exposure to a continuous burn, fire containment boom was capable of being air-deployed and used for containment purposes without loss of freeboard and without damage following exposure to ice abrasion.
- The fire containment barrier would have provided an effective means of containing oil in the lee of an island with 4 to 7 oktas of ice drifting by.
- The boom shows promise of providing an effective barrier in the free-floating mode among low ice coverages where oil will tend to drift faster than the ice and accumulate against such a barrier. Such concentrations might then be ignited from the air or from surface craft.
- The wave-following and handling characteristics of the boom appear to be as good as, if not better than, most conventional booms of similar size, strength, weight and cost.

APPENDIX

Task Descriptions as Developed by the Technical Committee

NOTE:

The task descriptions contained in this Appendix were modified somewhat in the field during the actual demonstrations. These changes were agreed upon by industry and agency personnel and were reflected in the demonstrations as described in Sections B and C of this report.

TASK 1

IN-SITU BURNING OF OIL IN SCATTERED ICE

OBJECTIVES:	Determine effectiveness of igniters and in-situ burning on water among scattered ice floes. Assess interaction of oil and ice prior to, during and following the burn.
LOCATION:	Onshore pit at Prudhoe Bay (approx. 100 yds. x 100 yds).
OIL REQUIRED:	1 to 6 bbls of Prudhoe Bay crude oil.
TIME/CONDITIONS:	Late May to early June with ice concentrations of 3 to 5 oktas.
DURATION:	1 to 3 days estimated.
SPECIFIC TSASKS:	Place the oil at a location in the pit where it will mix with broken ice ranging from 3 to 5 oktas in coverage. Document interaction of oil and ice. After 2 to 24 hours, ignite oil on upwind side and document complete burn (videotape and still photography). Remove and weigh burn residue using manual labor and other techniques as appropriate.
EQUIPMENT:	Prudhoe Bay crude oil (1 to 6 bbls). Igniters and other incendiary devises. Hand tools, garbage bags, safety gear, etc. Oil spill cleanup equipment as appropriate. Photo/video documentation equipment. Tape Recorders.
EVAULUATION CRITERIA: amount	Quality of oil burned, quantity recovered, and remaining in the pit following the burn. Number of igniters needed. Man hours required for cleanup.
DOCUMENTATION:	Aerial and surface photographs. Written log of all events and measurements. Tape recordings to back up log entries. Videotapes with live narration and real time superimposed on screen.

TASK 2

IN-SITU BURNING WITH FIRE CONTAINMENT BOOM

OBJECTIVES:	Demonstrate effectiveness of a treated conventional boom for in-situ burning.
LOCATION:	Onshore pit at Prudhoe Bay.
OIL REQUIRED:	Prudhoe Bay crude oil
TIME/CONDITIONS:	Late May to early June Adequate visibility for photography 0 to 15 knot winds
DURATION:	1 to 2 days
SPECIFIC TASKS:	Fire conventional boom Place fire containment boom (in 10-ft-diameter circle) in pit containing water. Place crude oil (up to 1 in. thick) inside boomed area. Ignite oil on upwind side and document complete burn (videotape and still photography). Remove and weigh burn residue. Repeat experiment, but feed a continuous flow of oil inside the boom over an extended period of time. Remove fire containment boom and inspect its condition.
EQUIPMENT:	Fire containment boom Prudhoe Bay crude oil Igniters Sorbents, handtools and hip waders for manual cleanup Photo/video documentation equipment Tape recorders
EVALUATION CRITERIA:	Structural integrity of boom following burn. Containment of oil prior to and during burn.

DOCUMENTATION:	Aerial and surface photographs Written log of all events and measurements Tape recordings to back up log entries Videotapes with live narration and real time superimposed on screen

(If the modified conventional boom is ineffective as a fire containment boom, it may be necessary to demonstrate the use and eployment of a fireproof boom)

TASK 3

OPERATION OF ARCAT IN BROKEN ICE AND OPEN WATER

OBJECTIVES: Determine ARCAT's ability to safely maneuver and encounter oil in broken ice.

Test mechanical and operational performance of recovery systems.

LOCATION: Offshore, preferably 2,000 feet or more downdrift from a drilling island, in the Beaufort Sea or some other suitable location with 2 to 4 oktas moving ice.

OIL REQUIRED: None.

TIME/CONDITIONS: Good visibility for vessel movement amongst ice floes and for aerial photo-documentation of ice conditions and drift patterns.

Ice concentrations of up to 4 oktas Sea State 0 - 2.

DURATION: 1-2 days with 2 simulated skimming periods of 4 hours each interspersed with transit to an offloading location.

SPECIFIC TASKS: Test stability, maneuverability and speed when skimming and in transit amongst broken ice.

Test the ability to maintain a relative position and skim in broken ice.

Test the operation of the rope mops and weir for their interaction with water and ice.

Test the potential for oil recovery in proximity to ice edges of slowly drifting floes.

Test offloading procedures and equipment.

EQUIPMENT:
ARCAT with crew (3 observers max)
State helicopter for observation and documentation
Photo-video documentation equipment
Tape recorders, stop watches

EVALUATION CRITERIA: (1) Safety
Vessel response to ice impacts
Visibility
Onboard features (railings, handholds, sharp corners, hot surfaces, non-slip grids, noise levels, etc.) (Coast Guard approved)

EVALUATION CRITERIA (continued):

(2) Maneuverability
Seakeeping characteristics, empty and fully loaded
Control of speed, turning ability maintaining station and negotiating through broken ice

(3) Oil Encounter/Recovery
Hydrodynamics of hulls at speeds of 0 to 3 knots
Action of rope mops and weir in water and ice including mop travel topside and wringer mechanism operation
Control coordination of mop and vessel speed

(4) Ice Considerations
Action of ice chunks at prows, in interhull area and response of mops and weir including ice accumulations
Accessibility of vessel amongst floes and at ice edges

EVALUATION STANDARDS: Stability and control in ice coverage to 4 oktas.

Ability to maintain station in and negotiate through 4 oktas of ice.

Successful operation of rope mops in ice infestations.

Offloading procedure of one hour.

Minimum interference resulting from action of hulls and ice.

Transit speed of 8 knots in open water and skimming of 1-2 knots in broken ice.

TEST PROCEDURE: Four hour intervals would be spent in maintaining a position, traversing ice floes in a chasing mode and maneuvering in close proximity to floes to simulate oil recovery at or near ice edges. Speeds would be recorded at which the vessel could operate amongst floes. Offloading collected water would be undertaken between skimming assignments. All procedures would be observed and timed with an emphasis placed on determining the operational capability of the ARCAT in relation to ice dynamics, open water and projected spill behavior.

DOCUMENTATION: Aerial and surface photographs

Written log of all events and measurements including vessel and mop speeds, skimming mode and location, ice coverage and ARCAT response.
Tape recordings to back up log entries.
Videotapes with live narration and real time superimposed on screen.

TASK 4

SUPPORT CAPABILITIES OF BARGES AND TUGS IN BROKEN ICE

OBJECTIVES:	Demonstrate logistical support capabilities utilizing tugs and barges in broken ice.
LOCATION:	Offshore in the Beaufort Sea
OIL REQUIRED:	None.
TIME/CONDITIONS:	Mid-June to late-July; breakup (with 5 to 6 okta ice coverage).
DURATION:	1 to 4 weeks depending on weather, ice conditions and nature of support for other demonstrations.
SPECIFIC TASKS:	Observe operation to be performed by Crowley Maritime Corporation to recover 14 barges stranded near Barter Island in mid-October 1982. Recovery operation scheduled to begin on July 1, 1983, or as soon as ice conditions allow, and will occur in water containing up to 6 oktas broken ice. Record weather, ice conditions, vessel operations, problems encountered, etc.
EQUIPMENT:	Helicopter for observation and documentation Photo/video documentation equipment Tape recorders
EVALUATION CRITERIA:	Success of Crowley operation in 5 to 6 oktas broken ice
DOCUMENTATION:	Aerial and surface photographs Written log of all events and measurements Tape recordings to back up log entries Videotapes with live narration and real time superimposed on screen

TASK 5

OPERATION OF ROPE MOPS FROM BARGES IN ICE-INFESTED WATERS

OBJECTIVES:	Test the applicability of rope mops in broken ice conditions when operated from vessels of opportunity.
LOCATION:	Offshore in broken ice.
OIL REQUIRED:	None
TIME/CONDITIONS:	2 to 4 oktas ice coverage.
DURATION:	Over suitable length of time to demonstrate capability in various ice conditions (2-day period desirable) (1 week for observers).
SPECIFIC TASKS:	Test the mobilization, deployment and operation of a rope mop so that it is used from a barge in broken ice. Examine the capability of the rope mop over 8 hour periods to contact areas of open water. Evaluate the effects of ice pieces of all sizes on the continuity of the operation, the need for repositioning, the durability of the polypropylene mop and wringer mechanism, and ice accumulations or other effects of ice. Record all data relating to skimmer operations, including problems encountered, operational procedures identified and repairs undertaken.
EQUIPMENT:	Tug and barge Rope mop skimmer(s) Helicopter Photo/video documentation equipment Tape recorders
EVALUATION CRITERIA:	Ability to operate rope mop from barge in broken ice Ice effects on skimming operations Percent of time the rope mop contacts open water areas and is operating
EVALUATION STANDARDS:	Percent of operation time in 2-4 oktas of ice for a period of 8 hours The ability to reposition the rope mop as necessary and to deal with problems caused by the ice as these arise
DOCUMENTATION:	Aerial and surface photographs Written log of all events and measurements Tape recordings to back up log entries Videotapes with live narration and real time superimposed on screen

TASK 6

BOOM DEPLOYMENT IN BROKEN ICE

OBJECTIVES: Demonstrate that the boom can be deployed to contain oil in the open water area developing in the lee of a drilling island in general ice coverage of 4-6 oktas.

Demonstrate that the boom can be deployed to contain oil in broken ice remote from the island when 3-5 oktas ice conditions are present.

Demonstrate that the boom can be used for mechanical recovery and in-situ burning and can be retrieved.

LOCATION: Offshore in broken ice in the Beaufort Sea
(1) Immediately adjacent to a drilling island in open water on its leeward side
(2) In ice drifting pass the drilling island (Free floating mode)

OIL REQUIRED: None

DURATION: 2 to 4 days with a minimum of 1 day of use in each containment mode

SPECIFIC TASKS: Mobilize 500 feet of boom to drilling island.
Deploy boom on leeward side of the island.
Deploy boom near but removed from the drilling island in broken ice and allow it to drift with the moving ice floes.
Observe boom and record its configuration in changing, dynamic ice conditions, and assess its practicality.

EQUIPMENT: Helicopter, ACV, or workboats
Barge (if available because of other tests)
500 feet of boom
Anchor assemblies including placement buoys, chain and anchors
Photo/video documentation equipment
Tape recorders

EVALUATION CRITERIA: (1) Safety
Personnel safety in deploying, positioning and repositioning the boom as necessary
(2) Survivability
(3) Practicality
Configuration of the boom over time and the action of ice within it; access to the boom

EVALUATION STANDARDS: Reasonably safe

Successful boom deployment in lee of island in 4-6 oktas of ice

Successful boom deployment in 3-5 oktas icve cover remote from island

Ability of boom to remain intact throughout the exercise

Successful retrieval of intact boom

DOCUMENTATION:
Aerial and surface photographs
Written log of all events and measurements
Tape recordings to back up long entries
Videotapes with live narration and real time superimposed on screen

PART FOUR

SCIENCE AND TECHNOLOGY IN SUPPORT OF INDUSTRY

The final section of this volume includes examples of the types of studies and technological innovations that are being implemented in support of industry activities. Stagg, Kemp and Moir describe a creative research project initiated to predict peak water levels in the Mackenzie River during ice-jam breakup. Lobsiger and his associates discuss the uses of underwater photography as a monitoring tool in the Arctic marine environment. Barber, Taylor, Bolduc and Murty summarize a research programme on ice cover in Tuktoyaktuk Harbour, and Seddon describes the R & D conducted at AECL's Chalk River Laboratories which could be applied in the hydrocarbon industry.

ANALYSIS OF PEAK WATER LEVELS IN THE MACKENZIE RIVER AT BREAKUP

by

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ABSTRACT

Esso Resources Canada Limited is currently expanding its oil-production facilities at Norman Wells on the Mackenzie River in the Northwest Territories of Canada. One criterion for the design of the facilities is the highest water elevation of the Mackenzie River expected during their lifetime. This paper shows that the annual peak water level, which occurs during spring breakup, depends upon the type of breakup, and that a selective statistical analysis of the annual peaks resulting from the more extreme type of breakup may be used to estimate peak water levels for long return periods.

Breakups are generally of two types: "thermal breakup" and "ice-jam breakup". During a thermal breakup, low flow rates in the river permit the ice to melt and gradually disintegrate, thus resulting in lower peak water levels. In the ice-jam breakup, higher flow rates produce ice jams downstream, which in turn create higher water levels. Thus, to predict peak water levels for long return periods, only the ice-jam breakup is important, and only the peak water levels resulting from this type of breakup were used to statistically predict water levels for long return periods. For comparison, a survey of trees on Bear Island at Norman Wells was conducted to determine the maximum level of ice damage over a 233-year period. The level of ice scarring was found to be roughly consistent with statistical predictions of water levels.

1. INTRODUCTION

Esso Resources Canada Limited is currently expanding its oil-production facilities at Norman Wells, which is situated on the Mackenzie River in the Northwest Territories approximately 140 km south of the Arctic Circle (Figure 1). Since the bulk of the oil reservoir underlies the Mackenzie River, the expansion project requires the design and construction of facilities in and near the river. The range of water levels in the river is therefore an important design consideration. The spring breakup of ice results in water levels in the river as much as 10 m higher than the summer mean. These peak water levels have been measured every year for the last 11 years, but estimates of the peak water level over longer return periods are required. This paper attempts to show how two different types of breakup conditions result in two ranges of water levels, and uses the upper range to estimate water levels for long return periods.

2. WATER LEVELS

The mean water level elevations at Norman Wells typically range from a high of 43.5 m a.s.l. in the summer to a low of 39.0 m a.s.l. during the ice-covered winter months. (The deepest portion of the river bed at Norman Wells is approximately 35 m a.s.l.) Only during the breakup periods will the much higher peak water levels be attained. These peak water levels, which were determined each year by surveying the high water mark, are tabulated in Table 1 for the years 1973-1983.

From 1943 to 1972, only sparse recordings of daily average water levels during breakup were made. These recordings, however, have been referenced to different bench marks at different times along the river, and do not reflect the maximum "instantaneous" breakup water levels. As a result, they have not been included within the statistical analysis of peak water levels.

Table 1

Year	Elevation (m)	Rank	Probability of Exceedance
1973	48.92	6	6/12
1974	50.13	2	2/12
1975	49.52	4	4/12
1976	49.78	3	3/12
1977	48.99	5	5/12
1978	47.15	8	8/12
1979	46.11	10	10/12
1980	43.60	11	11/12
1981	48.66	7	7/12
1982	50.65	1	1/12
1983	46.70	9	9/12

Table 1. Peak water level measured each year during spring breakup. Water levels are referred to the Geodetic Survey of Canada (1980 survey) and are in metres above mean sea level. The elevations are ranked from highest (1) to lowest (11) with corresponding probabilities of exceedance.

MACKENZIE RIVER SYSTEM SHOWING LOCATION OF NORMAN WELLS

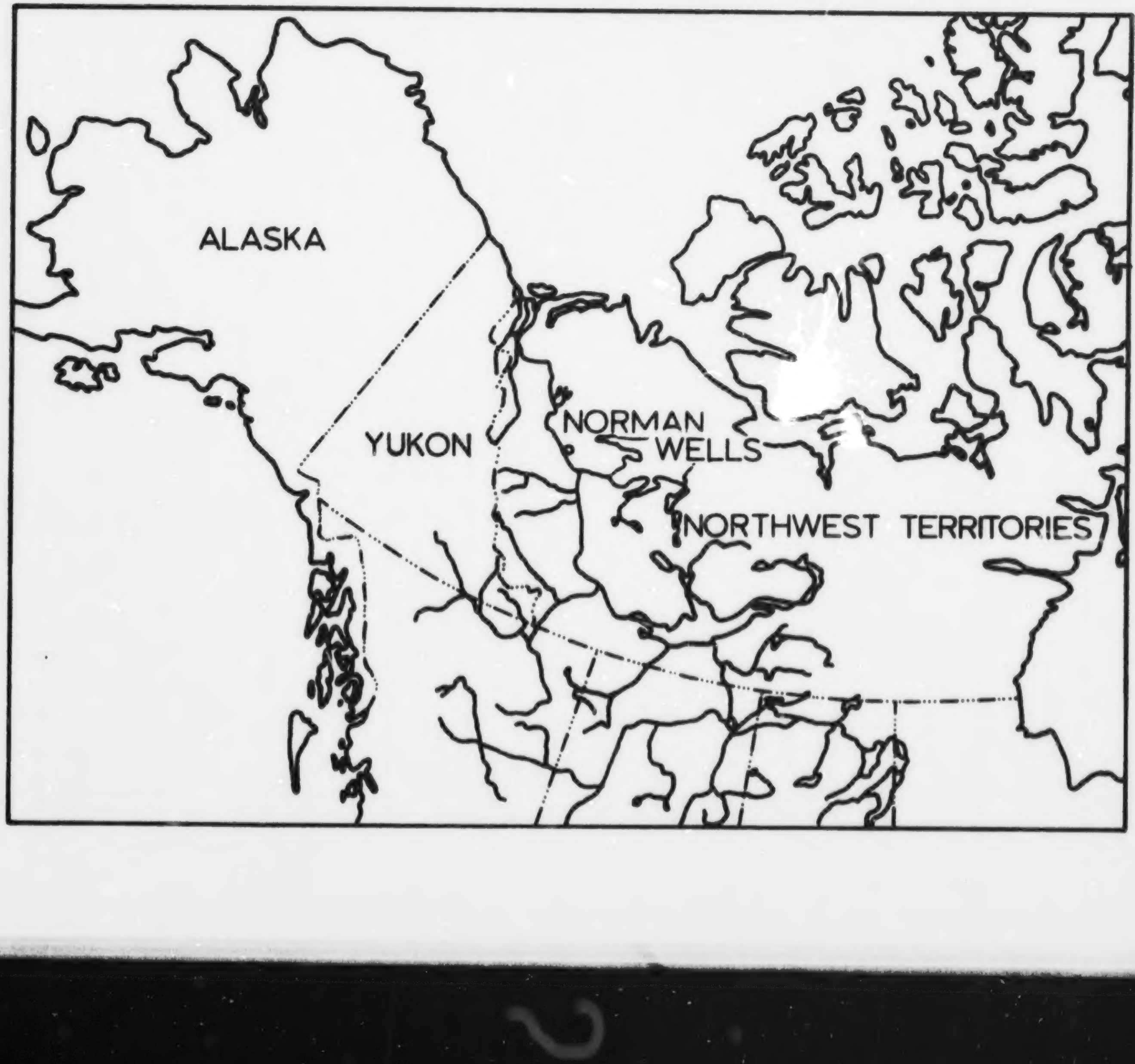
ALASKA
YUKON
NORMAN WELLS
NORTHWEST TERRITORIES

FIGURE 1

In order to present these data in the form of a probability plot, each peak water level must have an associated probability. This probability is simply the fraction of water levels which are greater than or equal to the water level in question. A number of relationships can be used to determine this probability or plotting position. Benson (1962), in a comparative study of several plotting-position relationships, found, on the basis of theoretical sampling from extrene-value distributions and the normal distribution, that the Weibull relationship provides the most consistent estimates of plotting position.

For data ranked from the largest (m=1) to the smallest (m=n), the Weibull relationship gives the plotting position, and hence the probability P_z, as

$$P_z(m) = m/(n+1), \qquad (1)$$

where z is a random continuous variable representing the water level (Table 1). Using the Weibull relationship to calculate plotting positions, the water levels in Table 1 are plotted on normal probability paper in Figure 2. The data do not fit a normal distribution (which would be indicated by their lying on a straight line); rather, two distributions may be distinguished: the upper seven points, which have a range of approximately 2 m and lie approximately on a straight line; and the lower four points, which have a wider range (3.5 m). The reason the peak water levels are distributed in this manner can be explained by examining the breakup conditions which caused the peak water levels.

3. BREAKUP CONDITIONS

The breakup of ice on the Mackenzie River is generally of two types--"thermal" breakup and "ice jam" breakup. Thermal breakup occurs when low flow rates in the river, accompanied by warm, sunny days, allow the ice to melt and disintegrate in place, then gradually break up and flow downstream. This produces the four lower water levels in Figure 2. Higher flow rates and lower temperatures, however, break up the ice and produce ice jams downstream. The resulting constriction in flow produces a backwater at Norman Wells, resulting in the seven higher water levels in Figure 2.

The two distributions are distinguished not only by the differing ranges of water levels, but also by the fact that the water levels associated with ice jams fall in a much narrower range than the thermal-breakup water levels. This can be explained by examining the breakup process and the flow rate.

In the spring, increased runoff slowly raises the floating ice sheet. As the main floating ice sheet rises, it gradually breaks away from the shorefast ice (ice frozen to the river bottom along the shorelines). This separation takes place along "hinged" cracks that form between the floating ice sheet and the shorefast ice during the winter. Short, ragged sections where the two ice masses remained attached constrain the floating ice sheet from moving downstream (Kamphuis and Moir, 1982).

During a thermal breakup, with low discharge, the ice sheet may be restrained by the shorefast ice contacts until the ice sheet has gone through a large degree of melting. This melting, caused primarily by solar radiation,

PEAK WATER LEVELS AT NORMAN WELLS
1973 – 1983

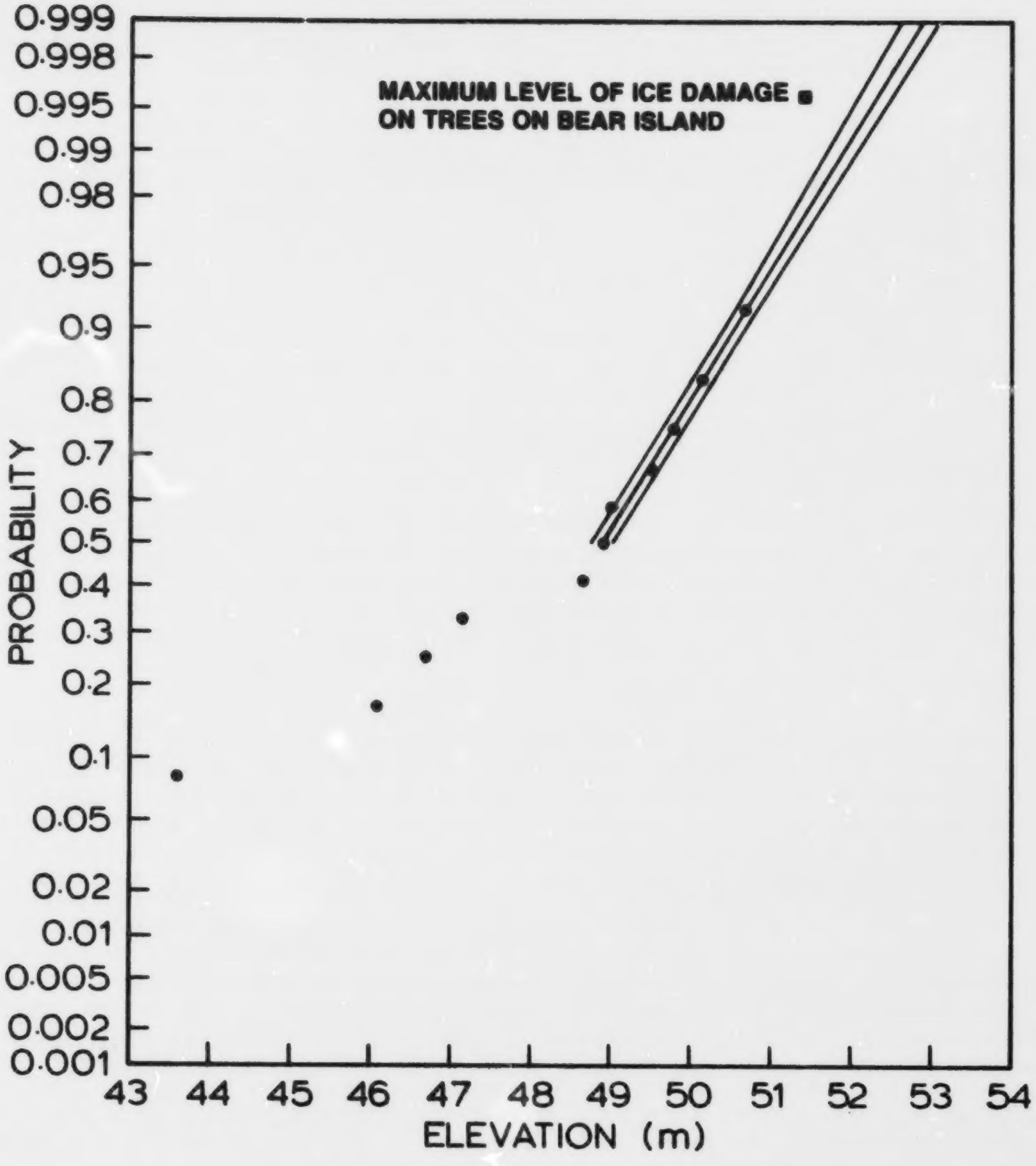

FIGURE 2

is in the form of candling (melting of the bonds between the longitudinal ice crystals within the ice sheet, resulting in ice "candles" weakly attached to each other). Also, the strength of the main floating ice sheet will depend upon how advanced the melting process is. Figure 3 shows the ice conditions during the thermal breakup in 1983. The large areas of open water between the ice pans and floating ice debris are typical of a thermal breakup.

During years when ice jams occur, higher discharge rates will raise and break the main ice sheet away from the shorefast ice sooner, allowing movement of the ice sheet before a large degree of melting can occur. As the stronger ice sheet moves downstream, it wedges in a narrow section of river 32 km downstream of Norman Wells and initiates an ice jam. A jam of this type is classified as a wide transition jam. The transition ice begins at the key, where a section of intact ice sheet is wedged between the shorelines. Backed up behind the key is a section of broken ice pans honeycombed with compression ridges, which progress into a section of thick, densely-packed ice debris further upstream. Finally, at the upstream end, the ice debris gradually thins out to open water. Figure 4 depicts the transition ice jam that formed through the Norman Wells area during the 1982 breakup.

Another distinguishing feature of an ice jam is flow rate. A certain flow rate in the river is required before enough shear is generated to breakup the ice in an otherwise thermal breakup and produce an ice jam. Thus the water must rise to a certain level before the critical flow rate necessary to produce the ice jam is attained. Figure 2 suggests that this water level is between 47.2 m and 48.6 m.

The lower limit for the water level is determined by the lower limit for the flow rate, which in turn is determined by runoff. Little snow and cold temperatures in the mountains of the Mackenzie River watershed (Figure 1) will significantly reduce the flow in the river during the breakup period. This explains the very low peak water level in 1980, when the breakup was observed to be very mild, and hence the wider range of breakup water levels during the four years of thermal breakup.

Once the critical discharge level in the river is reached, the increased drag from the compression ridges and the constriction in flow due to the thick, compressed ice debris which comprise the ice jam produce a backwater at Norman Wells, resulting in higher water levels. Several factors, however, combine to limit the peak water level in the backwater. As long as the flow rate into the jam is maintained and as long as the water level is rising, the width of the river increases, thus tending to free the jam of its shoreline constraints. In addition, the shear generated on the rough ice cover and the pressure arising from the hydrostatic head of water behind the jam generate considerable force on the jam, which becomes unstable and releases, allowing the backwater to recede and the water level to drop. The severe breakup conditions in 1982 produced a jam of this type. During the 1981 ice jam, lower discharge rates allowed the water level behind the jam to slowly drop, leaving ice debris from the jam to gradually rot and float away. From the graph of water levels shown in Figure 5 and from the range of ice-jam water levels discussed, it appears that an ice-jam breakup occurs in the Norman Wells area approximately two years out of every three.

4. ANALYSIS USING TWO DISTRIBUTIONS

Since the higher peak water levels occur only as a result of ice jamming, it is the ice-jam breakup which must be considered in statistically extrapolating to long return periods. The upper seven points (which correspond to ice-jam breakup) in Figure 2 lie approximately on a straight line. By extrapolating this line, the peak water levels corresponding to the longer return periods shown in Table 2 may be estimated. A Bayesian analysis described by Tang (1980) was carried out to determine the standard deviations shown in Table 2.

Table 2

Return Period (years)	Peak Water Level (± Standard Deviation) (m G.S.C.)
10	50.53 ± 0.13
25	51.13 ± 0.15
50	51.52 ± 0.17
100	51.86 ± 0.18
250	52.28 ± 0.20
500	52.57 ± 0.22

Table 2. Peak water levels estimated for various return periods by extrapolating the best least-squares fit to the seven highest points in Figure 2. The standard deviations were determined from a Bayesian analysis.

In order to provide a data point for comparison with this analysis, a study (Hardy, 1979) was carried out to determine the maximum elevation at which ice damage occurred to trees on Bear Island (at Norman Wells). Trees as old as 233 years showed damage no higher than 51.4 m a.s.l. It is not known whether the peak water level over the same period was higher or lower than the level of ice damage (or by how much). However, unless the peak water level was 0.8 m higher than the level of ice damage, it suggests that the analysis summarized in Table 2 is reasonable for estimating peak water levels.

5. SUMMARY AND CONCLUSIONS

An analysis of the breakup conditions in the Mackenzie River at Norman Wells suggests that there are two types of breakup: a mild thermal breakup with low peak water levels, and a more severe ice-jam breakup with higher water levels. The data for the ice-jam breakup were found to follow a normal distribution; extrapolation of this distribution to long return periods showed that even for a 250-year return period, for example, the predicted water level is 52.3 m a.s.l., which is 1.6 m higher than the highest water level observed in the last 11 years and 0.9 m higher than the level of ice damage to trees on Bear Island.

DISTRIBUTION OF PEAK WATER LEVELS AT NORMAN WELLS

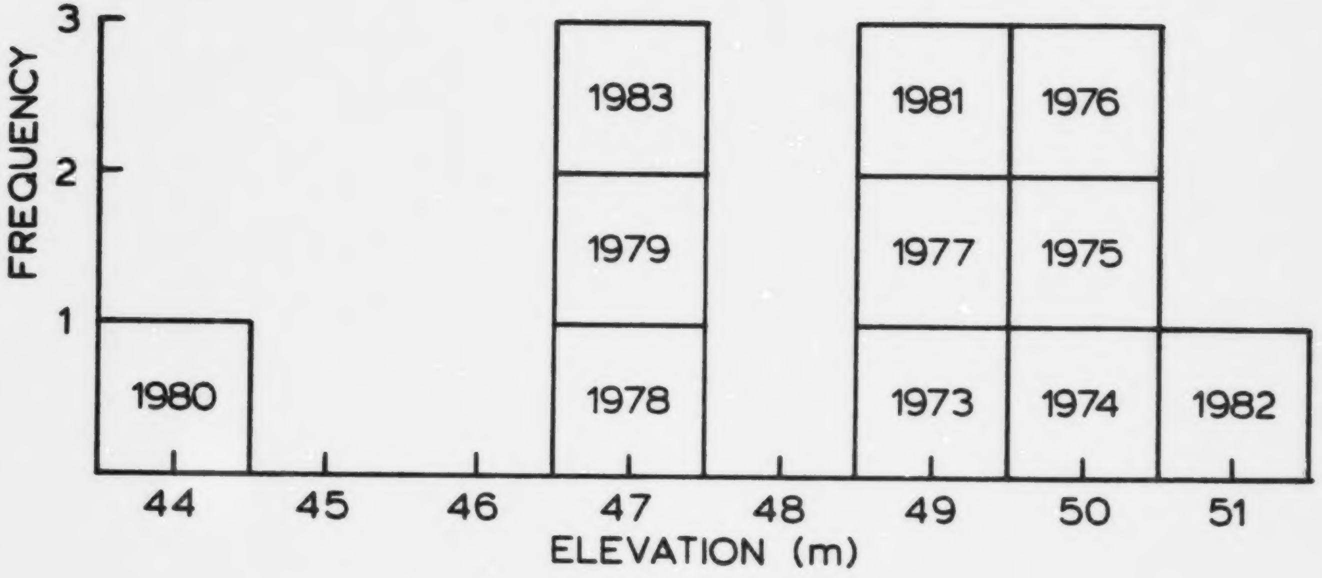

FIGURE 5

ACKNOWLEDGEMENTS

The authors wish to thank Esso Resources Canada Limited for permission to present this paper.

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UNDERWATER PHOTOGRAPHY AS A MONITORING TOOL OF MARINE ENVIRONMENTAL PROCESSES WITH REFERENCE TO ARCTIC CASE STUDIES

by

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ABSTRACT

In this paper, we discuss theoretical and practical aspects of quantitative still photography in the marine environment.

The capabilities of classical photography using film are compared to video monitoring and other electronic surveillance techniques. The theory of light absorption and scattering phenomena in seawater are described as they relate to picture quality enhancement in typical oceanographic applications.

The practical requirements for photogrammetric evaluation and stereophotography are presented.

Time series monitoring of benthic biota and sediment transport dynamics in Arctic near shore environments with practical considerations, including Arctic winter survey logistics, are discussed.

1. INTRODUCTION

Underwater photography is a well established method used to visually document characteristics of submarine features and the dynamics of oceanic processes.

Louis Boutan, a french marine biologist described the basic prerequisites for successful in-water photography as early as 1890. US oceanographers, notably researchers of the Woods Hole Oceanographic Institution and the Lamont Doherty Geological Observatory, pioneered ocean-bottom photography at abyssal depth starting in the late 1930's (Ewing et al, 1967). With the subsequent introduction of photogrammetric techniques primarly adapted from aerial survey techniques, underwater cameras are now used as quantitative measuring tools by ocean scientists and offshore engineers. With due consideration of the properties of water which influence light propagation, high quality images can be obtained. Large-scale surveys of the ocean floor equivalent to aerial topography are not possible with optical methods, due to much higher attenuation of light in sea water as compared with atmospheric air. Regional mapping and precise recording of 3-dimensional shapes, marine organisms or man-made structures, however, are entirely possible.

High-resolution film used in frame still photography is still the best recording medium. TV cameras are steadily being improved. They are particularly useful in real-time reconnaissance work. Newly developed SIT cameras (silicon intensified tube) can operate at very low light levels (ASA as high as 2 million), and CCD instruments (charge coupled device), which use silicon chips as image compilers will soon be competitive both in still photography and in video monitoring (compare with Booda, 1981). Independently of the recording mode utilized, the quality of the optics and the type of illumination chosen to transfer an image across the water/air boundary are determining the information value of the final result. Considering this fact, classical photographic techniques with corrected optics and high-resolution film emulsions offer a number of advantages:

- completely self-contained systems consisting of camera, strobe, and battery pack, each housed in an individual pressure case can be lowered to full oceanic depths without the use of umbillical cables;

- still camera systems consist of components which can be safely and efficiently operated even under the most difficult conditions, i.e. on board ship, or during an Arctic winter field survey.

The aim of this paper is to present the optical background of underwater photography and to discuss several typical applications.

2. OPTICAL BACKGROUND

An underwater camera joins an object space of water with an image space in air through a pressure resistant transparent interface. The propagation of image forming light in water is influenced by attenuation composed of absorption and scattering, and across the interface by refraction effects.

2.1 Influence of optical properties of sea water on image formation

The photographic emulsion of a film in an underwater camera darkens in response to an amount of light energy it receives from the direction of an object during a time of exposition. None self-luminous objects have to be illuminated by a light source to provide this energy. For those objects the light received by the camera consists of two parts:

- light reflected diffusely from the object's surface, which after being scattered on its way towards the camera produces the image of the object with spread contours;

- light scattered in sea water towards the camera, prior to reflection from the object, which results in lowering the contrast between different points on the object.

This brief presentation of the problem reveals an important role of optical processes in sea water into which the light is engaged on its way from the ligth source to the object and then to the camera. We will discuss these now, briefly.

Light propagating through sea water is attenuated. The percentage of light lost from a beam in a 1 m path is a measure of attenuation and is called the attenuation coefficient c. The attenuation of light is a combined effect of absorption - which terminates the path of a photon, and scattering - which deviates it from the original direction of propagation. Therefore

$$c = a + b \tag{1}$$

where a and b are absorption and scattering coefficients, respectively. The absorption of light in sea water is mostly due to water itself and dissolved organic substances, while the scattering is caused by suspended particles (Jerlov, 1976).

To compare the extent of this process in sea water with that in distilled water and air, pertinent data are shown in Table 1. These relate to the green wavelength band only, where the coefficients assume minimal values, and are different in other bands, thus modifying the spectrum of the light source sensed by the camera.

Table 1

Typical values of attenuation, absorption and scattering and coefficients of different environments in green (0.50-0.55 μm) band.

Environment	Attenuation coefficient [1/m]	Absorption coefficient [1/m]	Scattering coefficient [1/m]	Source
COASTAL WATER	0.7	0.6	0.1	Tyler, 1961
OPEN OCEAN WATER	0.1	0.02	0.08	Tyler, 1961
PURE SEA WATER	0.04	0.02	0.02	Jerlov, 1976
ATMOSPHERIC AIR (0 height, midlattitude)	0.000015	<0.000001	0.000015	Handbook of Optics, 1982

The intensity of light removed from the beam by scattering in sea water, unlike in the absorption case, depends on the direction in which scattered light propagates relative to the direction of incident light. The percentage of light lost from the beam over a 1m path length and scattered into some direction is a differential measure of scattering efficiency of sea water and is called the volume scattering function. It is worth noting that the scattering coefficient is just an integral of the volume scattering function over all directions around a scattering element of volume of sea water. The volume scattering function reveals strong asymmetry of scattering between the forward direction (small scattering angle) and backward direction (large scattering angle) with an intermediate minimum at about 100°-130° (Fig.1).

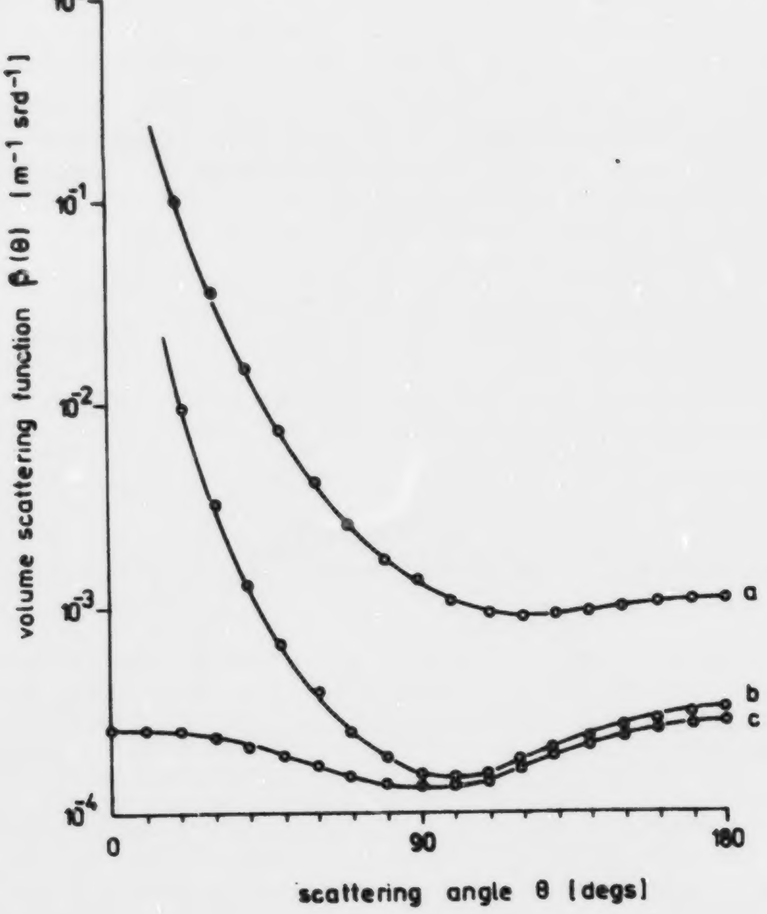

Fig. 1 Volume scattering function of different water types in the green band of the spectrum (0.5-0.55 μm)

a) coastal water	(Tyler, 1961)
b) open ocean water	(Tyler, 1961)
c) pure sea water	(Jerlov, 1976)

Let's now review briefly the influence of these processes on the formation of an image in an underwater camera. We will start with an idealized case of no scattering (Fig. 2a).

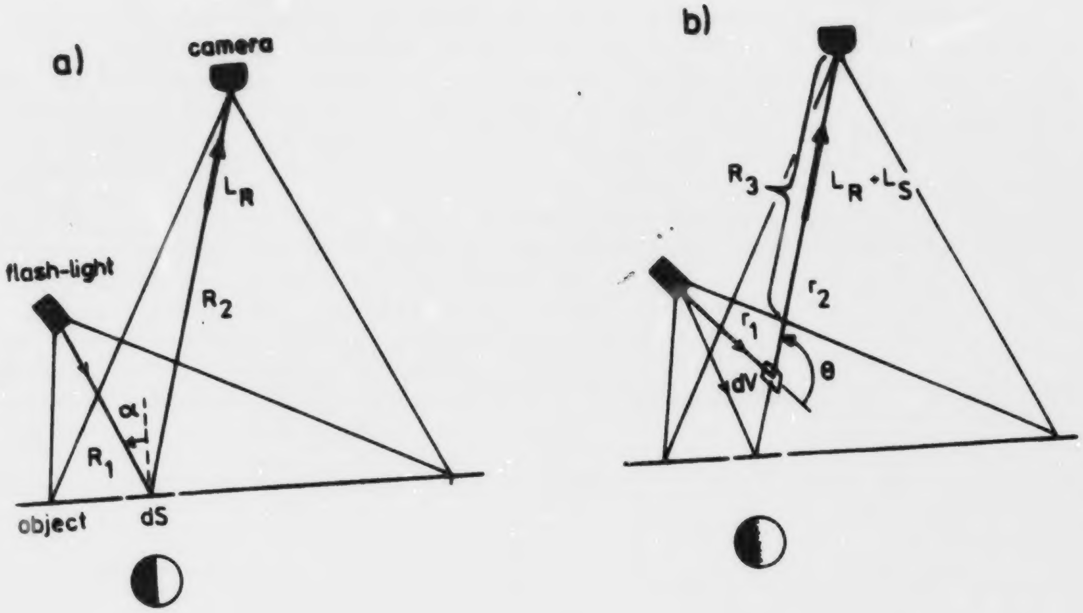

Fig. 2 Formation of image in underwater photography - demonstration of contrast degradation.

a) idealized case of no scattering of light by sea water - camera receives only light diffusely reflected from the object, good contrast

b) real sea water - camera receives also light in the water body, contrast decreases.

(symbols explained in the text)

The light from a light source (flash-light) is attenuated on its way R_1. The attenuation is due to absorption by water (and dissolved organic substances) - modifying the spectral composition of the light, and is also due to purely geometrical reasons: the further the illuminated element dS of the object's surface and the more it is tilted in relation to the direction of incident light (angle α) the less light it receives. Upon reaching dS the light is diffusely reflected, the amount to be sent towards the camera depending on the reflection coefficient of the object's surface at dS. On its way R_2 towards the camera the reflected light is again attenuated and arrives at the camera as L_R (for Reflected), the only light received in the no scattering case. Symbol L stands for radiance (Jerlov, 1976) which is a measure of light power received from a given direction per unit area of film's surface.

Introduction of scattering (Fig. 2b) modifies somewhat this component of total light energy received by the camera. This will be discussed under the topic of spreading of object contours at the image, and adds another component due to scattering of light from the light source by sea water towards the camera prior to reaching the object. The infinitesimal amount of this light dL_S (for Scattered) due to an infinitesimal element dV of sea water volume depends on the attenuation coefficient of water and the length r_1, the angle θ and the value of the volume scattering function at θ which determines the amount of light scattered by dV towards the camera. The scattered light is attenuated on its way to the camera in the same way as reflected light is. The overall amount of light, L_S, received by the camera from the direction towards the element dS of the object's surface can be obtained through integration over the distance R_2-R_3. This additional amount of light degrades contrast between different spots at the object much in the way shown in the lower part of Fig.2.

The obvious way to measure extent of this degradation is to use the quotient

$$\frac{L_R}{L_R + L_S} \qquad (2)$$

averaged over the object's area seen by the camera.

To improve the contrast it is necessary to minimize the term L_S, which can be done:

- optimizing a spatial arrangement of light source, object and camera according to optical properties of sea water - this being a subject of work carried by the authors;

- using polarizing filters to cut off the scattered light, most of which is polarized, but unfortunately reducing the useful light by 75 to about 100% (depending on the properties of the object's surface) (Briggs & Hatchett, 1965; Gilbert & Pernicke, 1966);

- range gating the light - opening the shutter only to accept the reflected light, which comes later than the scattered light (Heckman, Jr. & Hodgson, 1967);

- angle gating the light - scanning the object with narrow beam light source and similarly narrow beam receiver, thus minimize radically the scattering volume of sea water at the intersection of these two beams (Steigold & Strauch, 1968);

- processing the image to subtract the scattered light.

Only the last two ways can work in removal of another effect of scattering of light in sea water: spreading of contours of the object in its image, which is explained in Fig. 3.

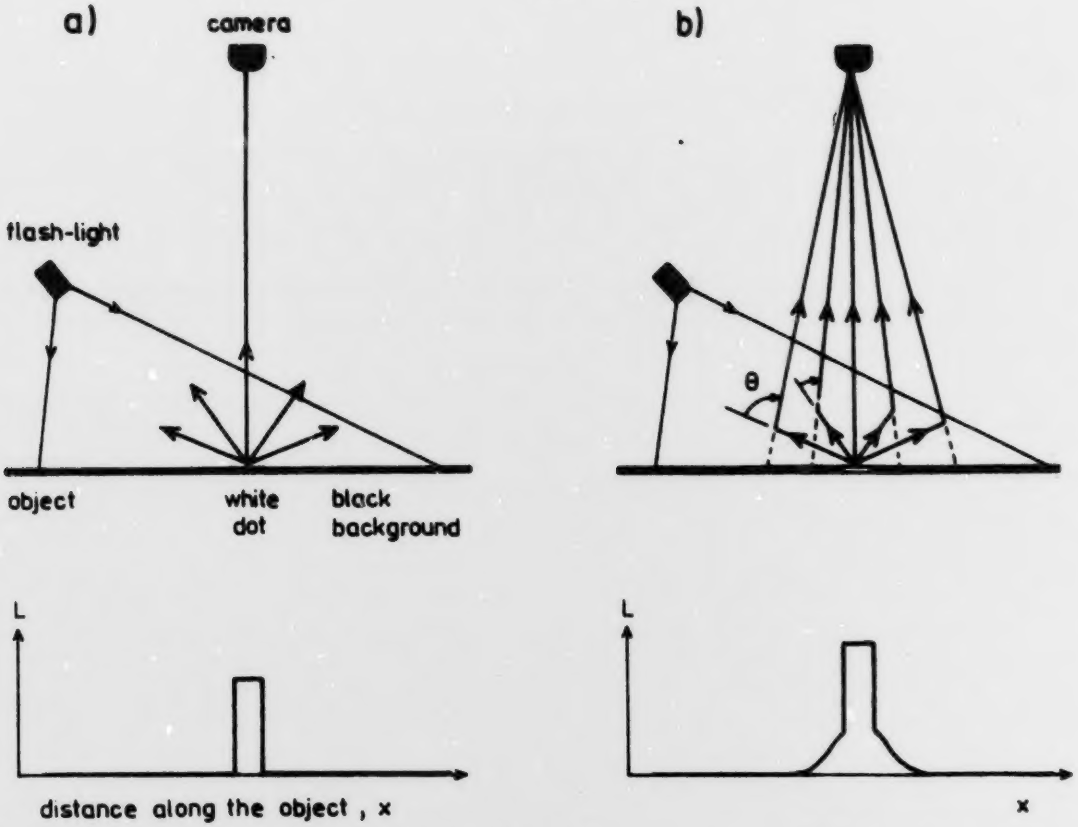

Fig. 3 Spreading of contours of an object in its image as seen by a camera.

a) an idealized case of sea water with no scattering - no spreading of contours of the dot

b) real sea water - light reflected from the object is scattered towards the camera enlarging angular dimensions of the dot - contours spreading.

(symbols explained in the text)

A simple object consisting of a white dot on a black background is the object there. In an idealized case of no scattering (Fig 3a) the camera receives only that part of diffusely reflected light which goes in its direction. Addition of scattering (Fig. 3b) causes some light which is propagated in other directions to scatter towards the camera. The apparent angular dimension of the dot increases and contour of the dot, sharply defined in the previous case (lower part of Fig. 3a), will spread resulting in a smooth distribution (lower part of Fig.3b) depending on the form of volume scattering function of the sea water.

2.2 Refraction effects

As a consequence of the different refractive indices of water and air, the apparent focal length for an object in water seen by an air lens through a protective port is augmented by a factor of approximately 4/3. Image distortion caused by refractive effects is corrected with three different approaches:

- an air lens is mounted closely behind a flat plate of a transparent, pressure resistant material, preferrably with a refractive index similar to water (e.g. acrilic).

- a glass dome is constructed to compensate for the distortions associated with refractive effects (Ivanov-Rebikoff corrector).

- the protective glass dome and the lens systems are calculated to form an integrated water contact lens (Mandler, 1970).

2.3 Underwater stereophotography

Three-dimensional imaging of underwater objects is performed with techniques similar to aerial phtogrammetry (Fig.4). It requires a stereographic pair of photographs made with particular attention to provide even illumination of the object as well as an optimal geometric arrangment of two cameras in relation to the object. The latter depends on characteristics of the lens, the watertight transparent port, and the stereo contour plotter. For 90° diagonal Leitz lenses (ELCAN C240, fully water corrected, Mandler, 1970) used by the authors, the optimal height, h, to base, b (Fig.4) ratio is about 1.5, to yield an image overlap of 60% (Kincaid, 1983).

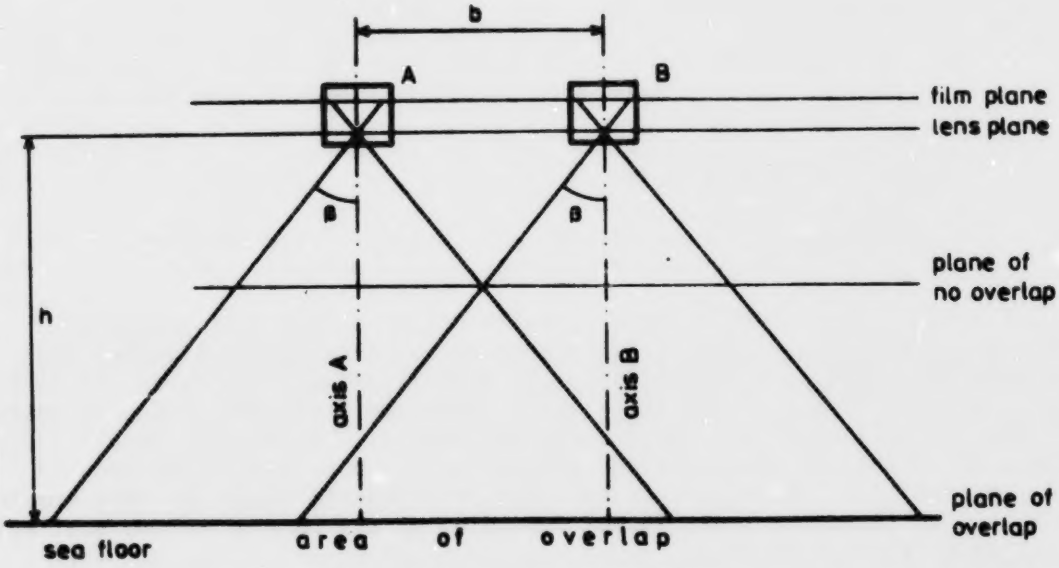

Fig. 4 Geometric arrangment for stereophotography with 90° diagonal angle lenses for 24 x 36 mm format.

3. Applications of underwater photography - recent studies by the authors

Our underwater photographic investigations are presently concentrated on applications for documenting benthic populations and underwater gas bubble phenomena. The pictures have been taken using commercial 35 mm reflex cameras packaged in a pressure housing and controlled by electronic timers and versatile trigger devices. New equipment, with the previously mentioned Leitz optics is now extensively being tested for full photogrammetric applications.

In a recent winter survey of an Arctic inlet (Carter and Thomas, 1982) one of our cameras was used to supplement benthos information gathered by grab sampling of 1 m^2 of ocean floor. The camera was lowered through a small diameter hole in 1.8 m thick ice by virtue of its collapsible tripod before any bottom disturbance had been caused by other sampling techniques. Upon impact of a trigger weight at the ocean floor, the first picture was taken and simultaneously a timing cycle was started to take 20 pictures at 1 minute intervals. This procedure was successfully carried out at 10 stations with both colour and B/W film. The photographs have a good indication of the short term behavior of benthic epifauna - in this case brittle stars and burrowing anemones. Considerable lateral and vertical movement was easily observed with the use of these photographs. The ability of the photographic equipment to yield information valuable in benthic studies was fully demonstrated.

In another recent application of this equipment, large scale gas discharges were documented photographically (Woodward, Lobsiger and Johnson, 1983). This study was carried out in the Aquatron Tower Tank of Dalhousie University. Air and CO_2 were streamed through sea water to simulate off-gas venting from an offshore natural gas field. The size distribution of the steady-state bubble populations at various flow rates were measured using pictures made by the underwater camera equipped with back-lighting of bubbles. A lucite collar in front of the lens was applied to force bubbles to rise in and behind the focal plane set at 30-40 cm. Sharp-edged images of the bubbles were achieved using high-contrast film. Bubbles outside the focal plan appeared with blurred edges and were eliminated from the count by an image analyser (Joyce-Lobel Magiscan) by defining an "edge-sharpness" criterion. The size distribution measured using this instrumentation confirmed theoretical models.

Quantitative underwater photography offers great potential in geotechnical investigations as well. Erosion patterns around a leg of a jack-up platform or on the slope of an artificial drilling island can be photographed over time periods of days to months. A system consisting of one or two cameras, a flash unit and longlife battery pack is rigidly mounted, pointing at the area of interest. A user programmable microprocessor will trigger the camera at preset time intervals, e.g. to follow tidal cycles, or in a feed-back mode during a storm or discharge event. Markers placed into the field of view will then allow quantitative evaluation of images. Stereophotography is most promising for those cases of fixed structures, limited mapping, however, is also possible upon providing good control of tilt angles and ground truthing. With our wide-angle optics, which provide undistorted and sharp pictures over the full film frame, considerable areas can be photographed despite the distance limitations due to attenuation effects (Table 2).

Table 2

Area coverage with 90° diagonal ELCAN lens.

Distance (m)	Area (m^2) Single lens	Area (m^2) Stereopair (60% overlap)
0.3	0.17	0.10
0.74	1.0	0.60
1.8	6.0	3.60
6.0	66.50	40.0

The maximum camera-to-object distance of 6 m is about the limit in clear open ocean water using normal illumination techniques. A typical camera with 250 frames would thus allow an accurate mapping of an area of 100 x 100 meters.

Ongoing studies on the Scotian Shelf prove the usefulness of the technique both for benthic studies and for sediment movement documentation over short and longer time intervals.

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INFLUENCE OF ICE COVER ON RESONANCE PHENOMENA IN TUKTOYAKTUK HARBOUR

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ABSTRACT

Tide gauge obsersvations in Tuktoyaktuk Harbour were analysed through spectrum analysis to understand the influence of ice over on the various tidal constituents, as well as free oscillations. The tidal constituents studied here included the semi-diurnal constituents M_2 and S_2; the diurnal constituents K_1 and O_1; and several shallow water constituents. The normal modes included in this study are one-quarter resonant wave length of the Herschel-Bathurst Shelf, the first edge wave mode of the same shelf, the free oscillations of the Amundsen Gulf, Kugmallit Bay and Tuktoyaktuk Harbour; and finally the Helmholtz mode of the same harbour. It is shown that the ice cover has varying degrees of influence on each of these modes and tidal constituents.

1. Introduction

There is growing observational evidence that long gravity waves in a water body are affected by an ice cover at its surface. Murty (1977) speculated that one of the reasons tsunamis do not appear to get amplified in waterbodies at high latitudes may be the dissipative action of ice cover. Murty and Holloway (1983) showed that positive storm surges are damped much more strongly than negative surges by an ice cover. Godin (1980) and Kowalik (1981) discussed the influence of ice cover on tides: in particular Godin showed that the tide is not modified significantly at sites in good contact with the deep ocean. On the other hand Kowalik showed that ice cover has significant influence on the M_2 tide in the Arctic Ocean, as can be seen from a comparison of his Figures 3 and 12.

Hamblin (1976) suggested that the ice cover of Lake Winnipeg probably influences the character of seiche activity there and Schwab and Rao (1977) considered that the absence of clear peaks in certain spectra for Saginaw Bay may have been due to the ice cover. There are many bodies of water where the ice cover likely alters some aspects of the topography (shape, depth or the number of openings which provide coupling to the external ocean).

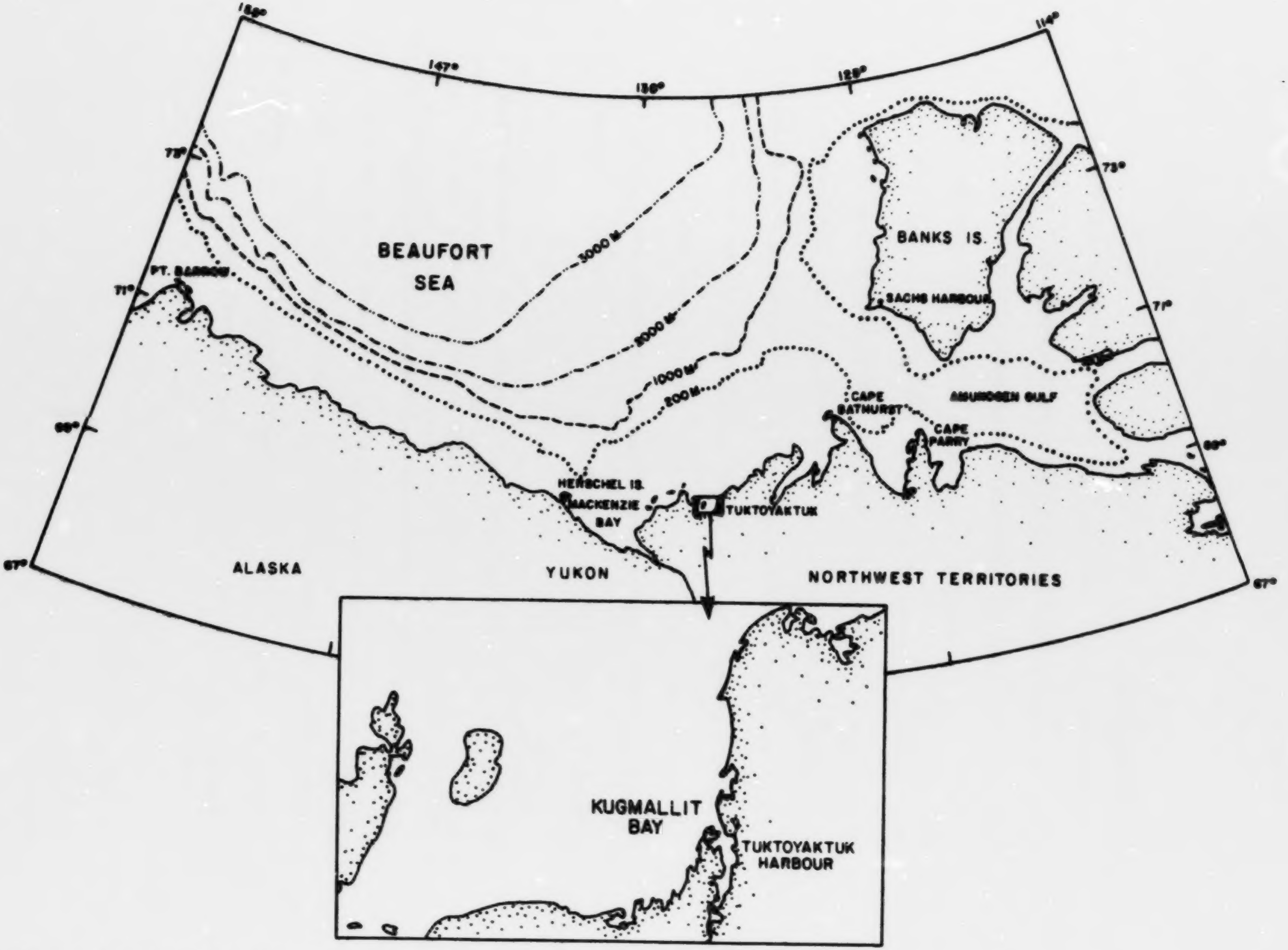

156°
147°
138°
129°
114°
73°
71°
69°
67°
BEAUFORT SEA
3000 M
2000 M
1000 M
200 M
PT. BARROW
BANKS IS.
SACHS HARBOUR
AMUNDSEN GULF
CAPE BATHURST
CAPE PARRY
HERSCHEL IS.
MACKENZIE BAY
TUKTOYAKTUK
ALASKA
YUKON
NORTHWEST TERRITORIES
KUGMALLIT BAY
TUKTOYAKTUK HARBOUR

Figure 1-Tuktoyaktuk harbour

2. Geography and Dimensions of the Water Bodies Involved

Figure 1 shows the geography of the southern part of the Beaufort Sea. The 200 m depth contour is assumed to be the seaward limit of the Herschel-Bathurst Shelf, which has an average depth of about 50 m and an average width of 108 km. We assume that the Amundsen Gulf extends from the narrowest portion of the Dolphin and Union Strait northwestward to the far edge of the Herschel-Bathhurst Shelf, i.e. about 300 N.M.; with an average depth of 200 m.

The shallow Kugmallit Bay connects the Tuktoyaktuk Harbour to the Beaufort Sea. The relevant dimensions of Kugmallit Bay for computation of its normal modes (free oscillations) are not certain. A length of 25 km and an average depth of 2 m was chosen for this purpose. This average depth of 2 m could be reduced to 1 m by ice cover, or increased to 3 m by a storm surge. In the Kugmallit Bay, by the end of winter, the ice cover could average 1.8 m (Bilelo and Bates, 1971). This winter ice cover causes a significant increase in the friction. Ice cover (polar pack) usually exists seaward off the shelf. According to Reimnitz and Barnes (1974) the configuration of Kugmallit Bay may be altered by ice cover, because parts of the bay are very shallow, and especially if a feature like "bottom fast ice" is present landward of the 2 m depth contour.

An ice cover might change not only the depth but the surface area, the area of cross section and the width of the openings. There is a difference in ice cover between Kugmallit Bay and Tuktoyaktuk Harbour (referred to as "harbour" in the subsequent discussion).

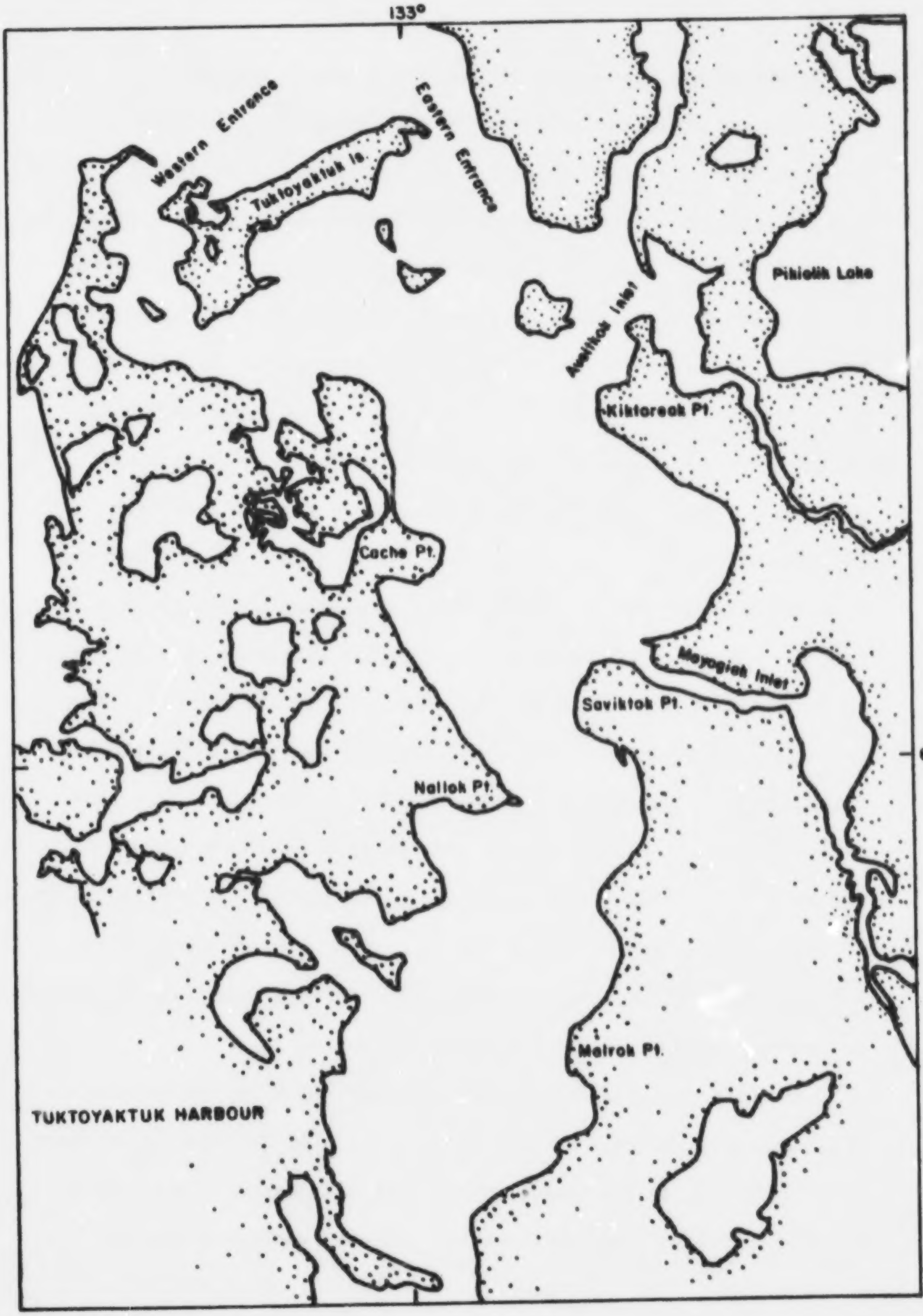

133°
Western Entrance
Tuktoyaktuk Is.
Eastern Entrance
Pikiolik Lake
Avalitkos Inlet
Kiktoreak Pt.
Cache Pt.
Mayogiak Inlet
Saviktok Pt.
69°25'
Nallok Pt.
Mairok Pt.
TUKTOYAKTUK HARBOUR

Figure 2-Tuktoyaktuk harbour

For a brief period in early summer the landfast ice of the bay undergoes breakup whereas the harbour ice remains landfast. Ice cover can alter the shape, depth and the number of ports of the harbour which provide coupling to Kugmallit Bay. The wetted shape of the harbour and the number and dimensions of the ports are influenced by the ice cover (the western entrance of the harbour might be closed entirely by ice). In the harbour also, the depth increases after the dissipation of the ice cover, and also during storm surges.

The harbour, located on the eastern edge of the delta of the Mackenzie River, is connected through eastern and western entrances to Kugmallit Bay (Figure 2). The harbour, which is at least 6.5 km long (and perhaps as long as 11.5 km) is not yet completely surveyed, and is 1.8 km wide and attains a maximum depth of 30 m. The limiting depth of Kugmallit Bay to the harbour (about 4 m) occurs just seaward of the entrances. The maximum depth in the western entrance appears to be less than 2 m, and at its narrowest point, it is only 40 m wide. For the computation of normal modes we took the length of the harbour as 11 km and its average depth as 5 m.

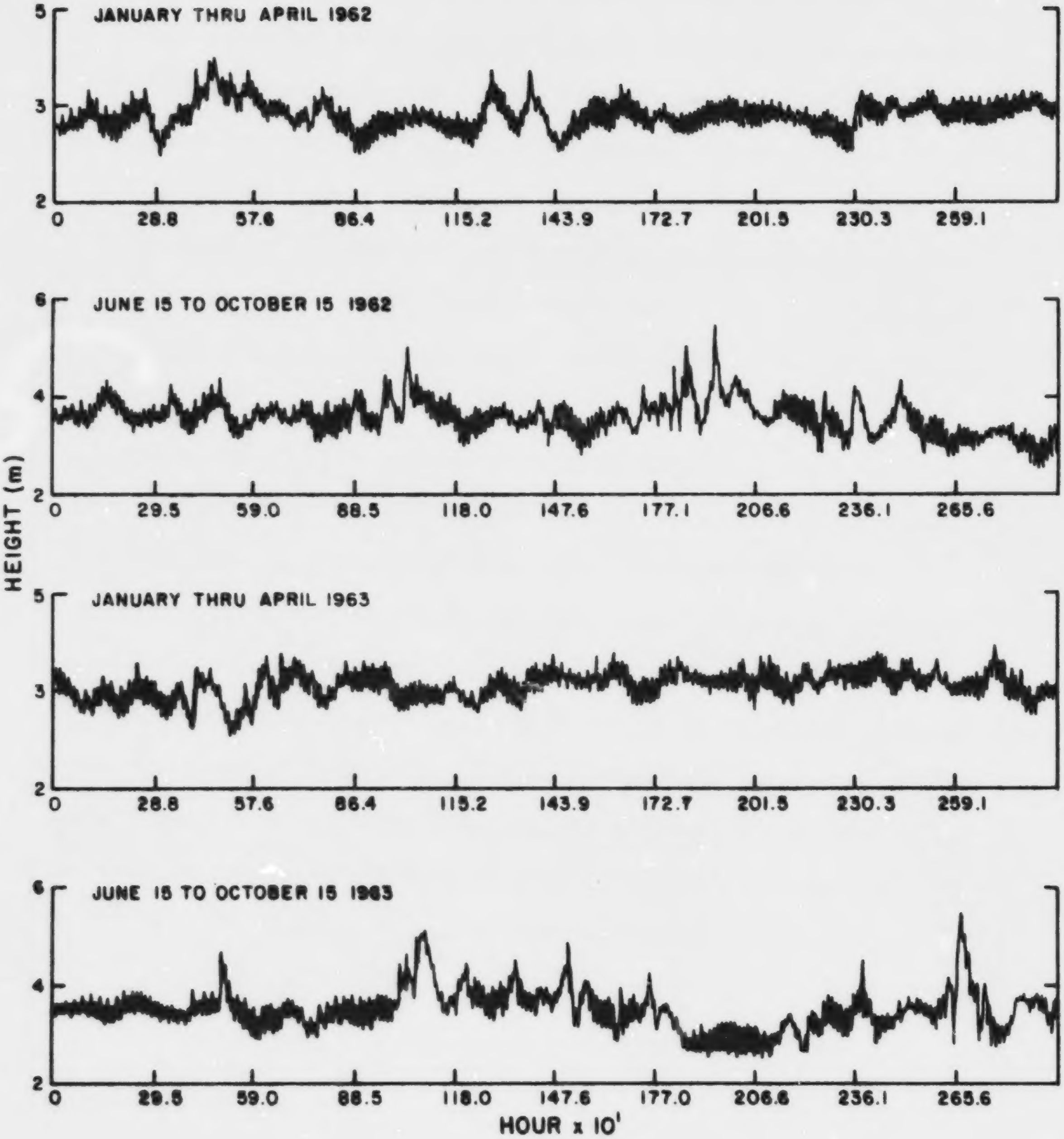


Figure 3-Tidal records 1962 & 1963

3. Observed Tidal Data and Spectral Analysis

The first tidal record for the harbour appears to have been obtained in the open season of 1933; the next one in the open season of 1952 (open season means ice-free period). Visual examination of the 1952 record indicates the existence of oscillations at frequencies other than tidal, probably due to natural modes (seiches) and due to storm surges.

The following tidal records at Tuktoyaktuk are of sufficiently good quality to be used for careful scrutiny: (a) January through December 1962 (b) January through December 1963 (c) January through August 1964 (d) January through August 1965 (e) January through June 1973 (f) July through December 1974. In this study, the period of January first through April thirtieth is considered as the time of ice cover; and the period during June 15th to October 15th is representative of the ice free period. Figure 3 shows the tidal records for the relevant periods in 1962 and 1963.

For the power spectral studies hourly water levels are used. Thus for the period of January through April, the total number of data points are 2,880. For the period June 15th to October 15th, the total number of data points are 2,952.

The data were pre-whitened using the first difference filter, the mean and the linear trends were removed, a one-tenth cosine taper applied to the ends of the series and then the data were zero-padded to the next higher power of two. The Fourier transform was then applied and the results re-coloured and scaled to give spectral density,

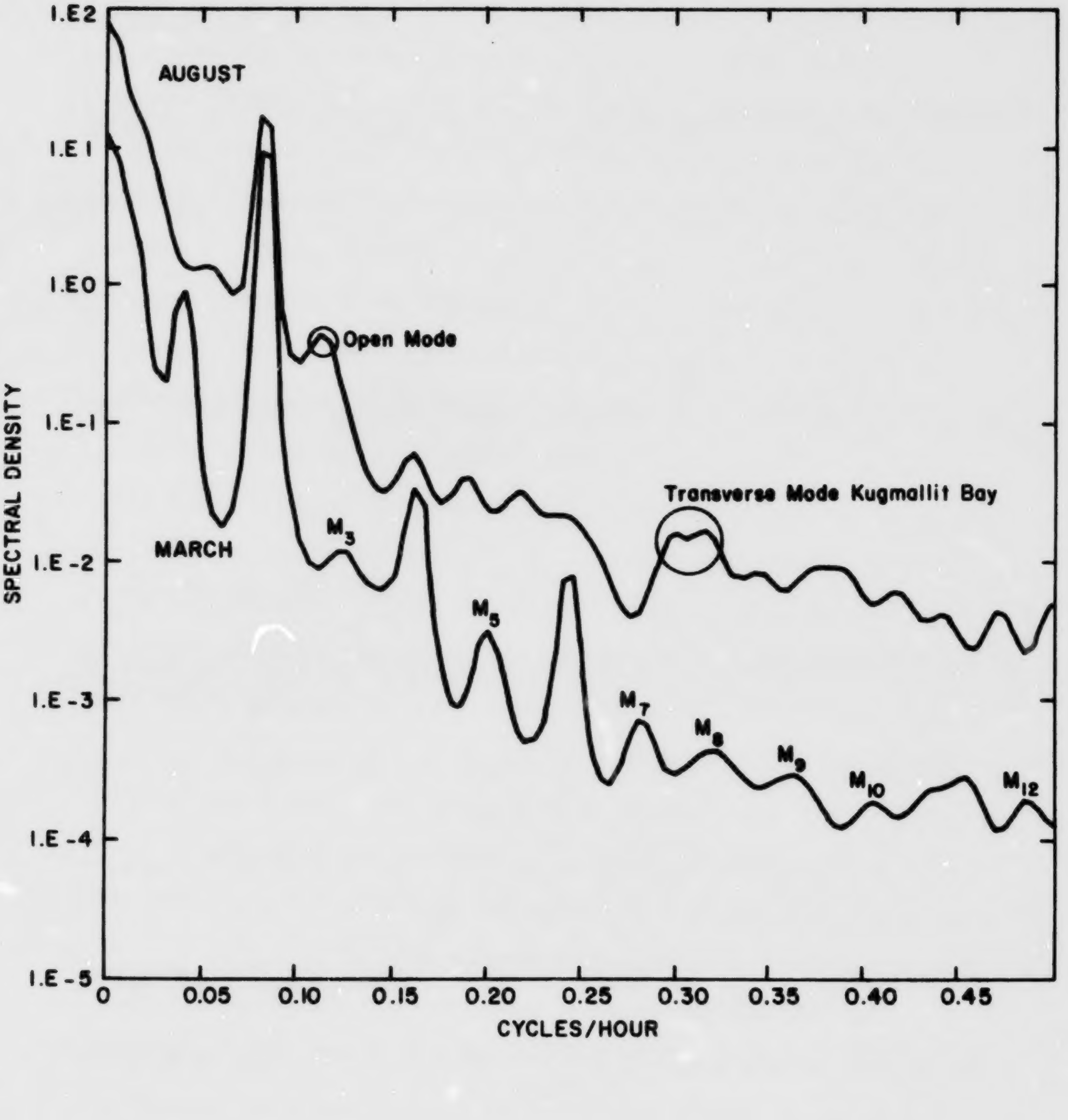


Figure 4-Power spectra for March & August 1962

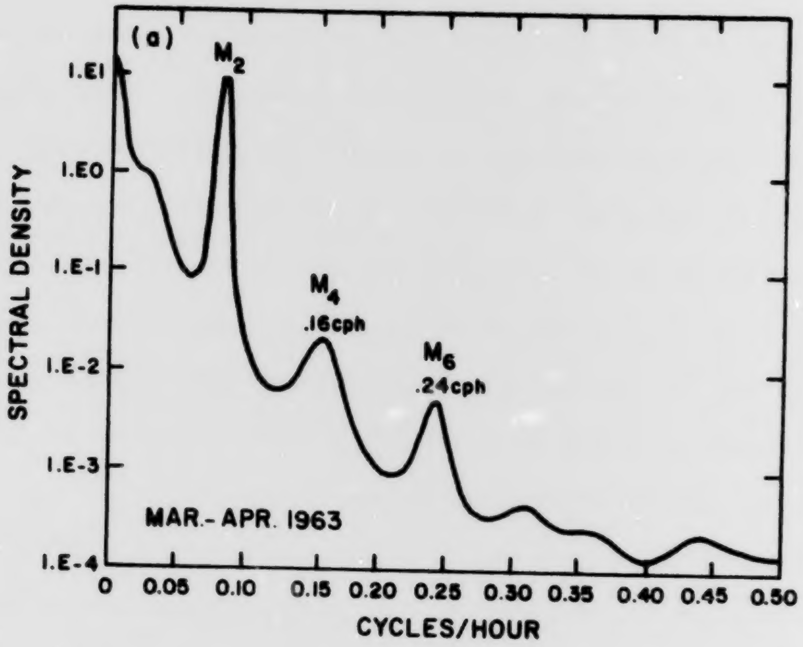


Figure 5a-Power spectrum March-April 1963

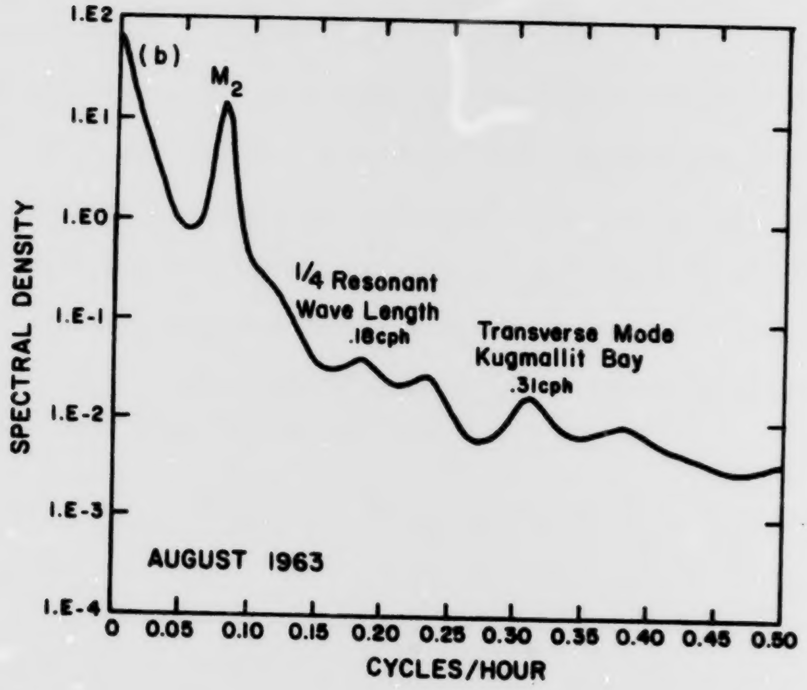


Figure 5b-Power spectrum August 1 63

after which the power was lumped into the specified number of bands. Since the interval of data sampling is one hour, the lowest resolvable period is two hours, and thus the highest resolvable frequency is 0.5 cph.

Figure 4 shows the power spectra for March (lower curve) and August (upper curve) of 1962. The top part of Figure 5 shows the spectrum for March - April 1963 and the bottom part for August 1963. Figure 6 shows the spectrum for the data set of January 1962 through October 1963. Figures 7,8,9 and 10 respectively show the spectra for the ice cover and ice free periods of 1962 and 1963.

To understand better the resonant oscillations in the harbour, as well as the modes of Kugmallit Bay and the Herschel-Bathurst Shelf, the data for June 21 (ice cover, no significant surge), August 26 (no ice cover, no significant surge), and August 31 (no ice cover, storm surge present) of 1962 were analyzed using a 15 minute interval, rather than the usual one hour interval. In this case, the maximum resolvable frequency is 2.0 cph rather than 0.5 cph. Figure 11 shows the spectra for these three days separately. Fifteen minute interval data are also used for the storm surge events of October 1-6, 1963 and January 4-8, 1974. The spectra for these two events are shown in Figure 12.

For the 15 minute data series, the maximum entrophy method of spectrum analysis is used. The mean height was removed before analysis and a variety of predictor filter lengths were used.

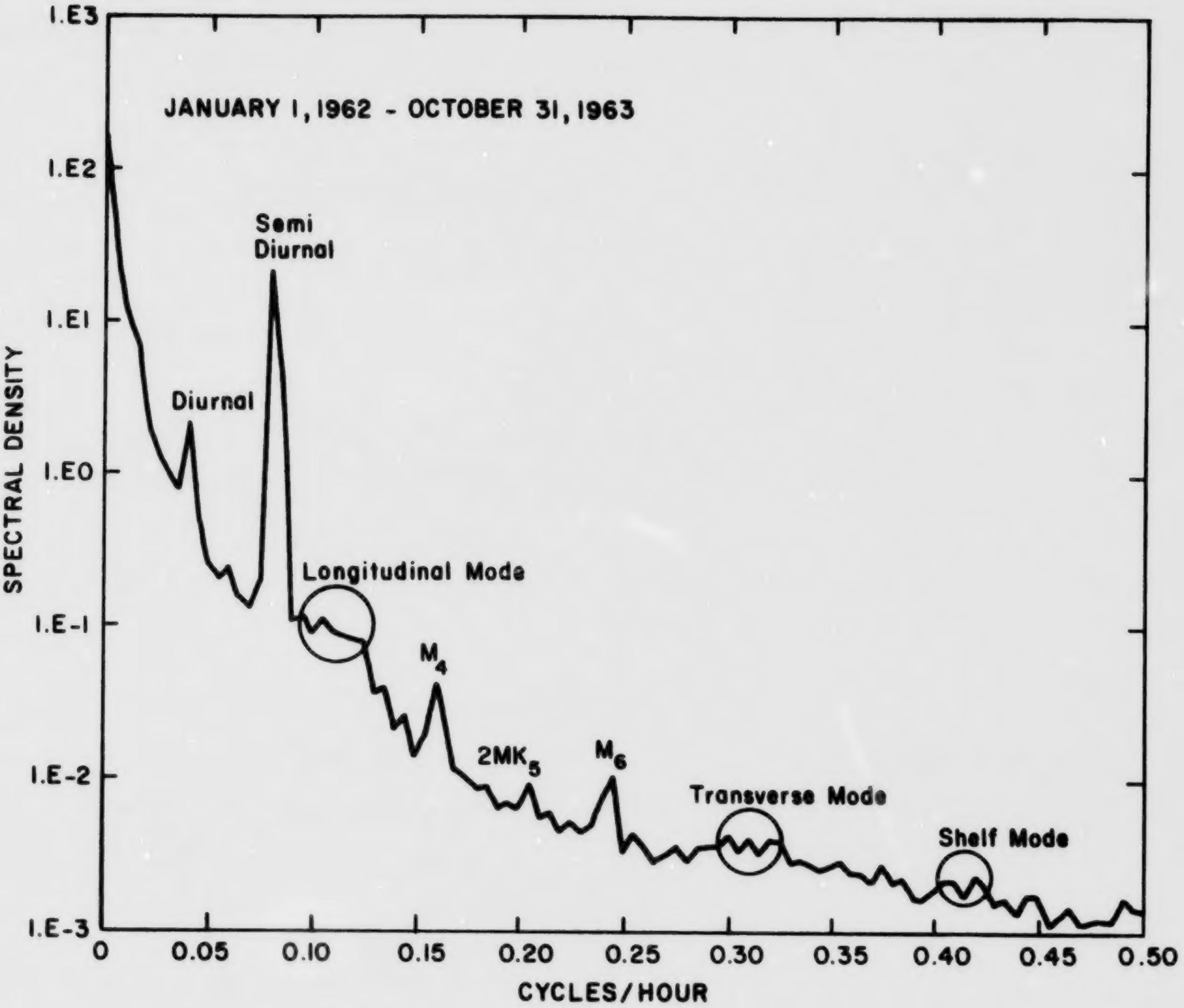


Figure 6-Power spectrum January 1962 to October 1963

Figure 7-Spectra for ice cover & ice free periods 1962

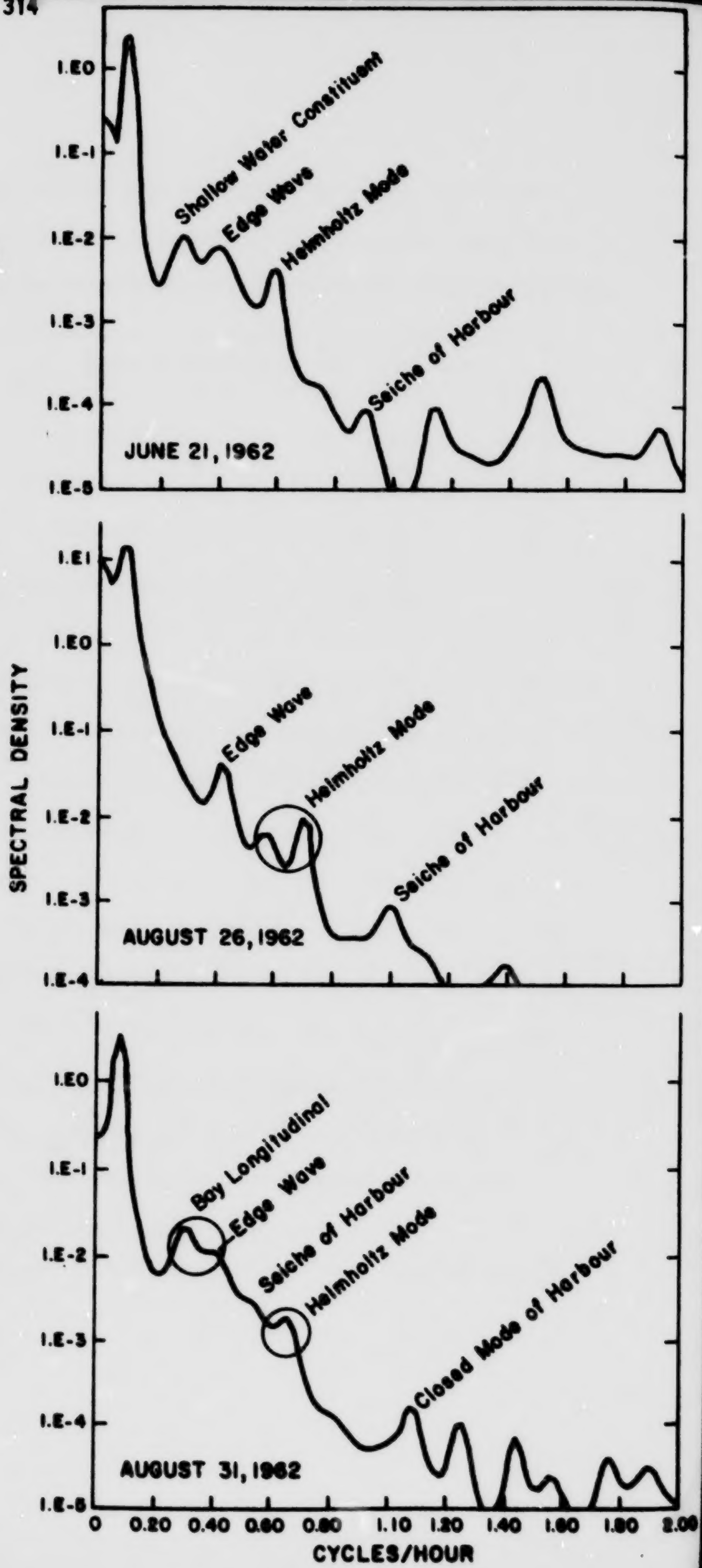
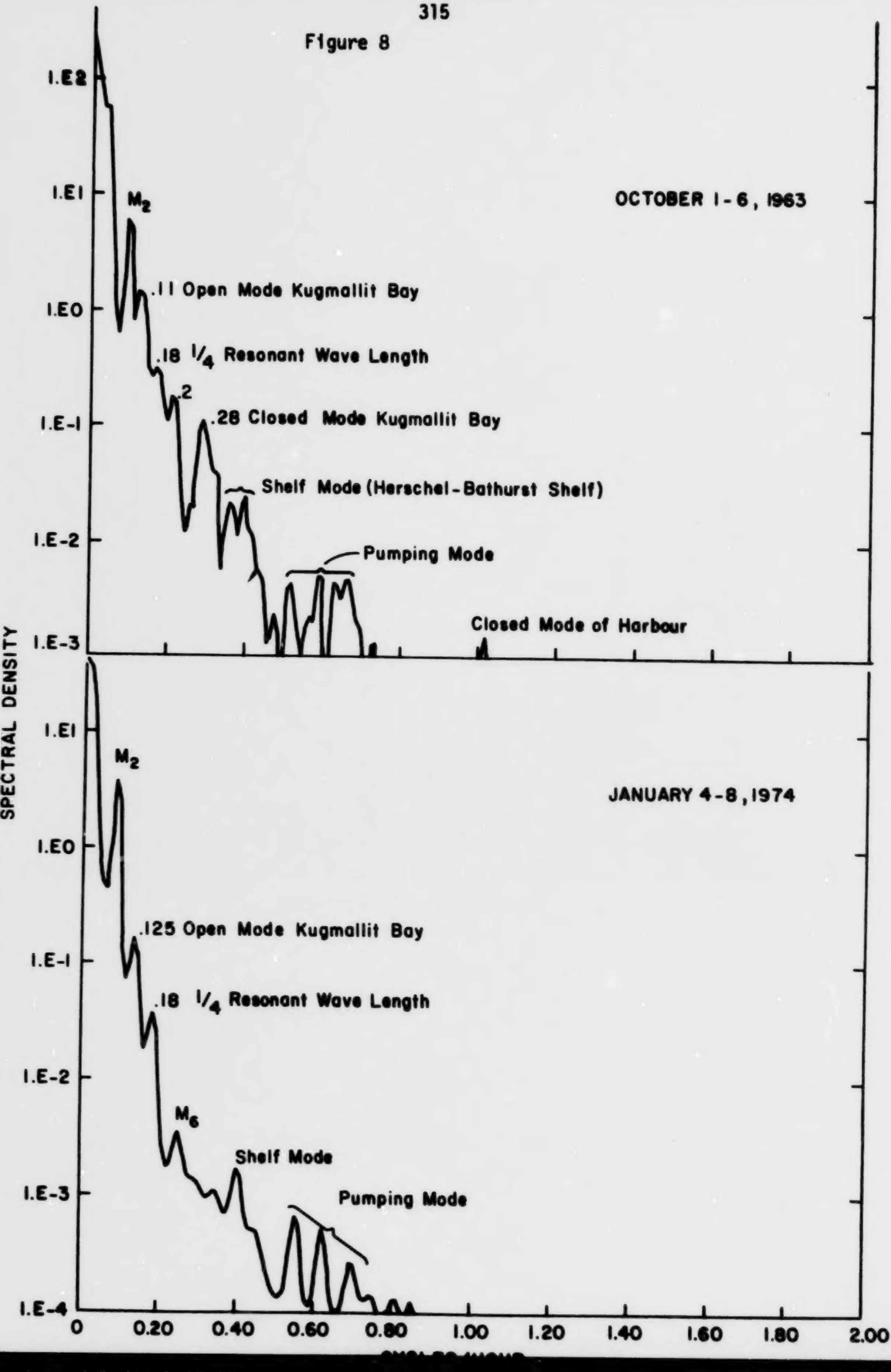


Figure 8


SPECTRAL DENSITY
OCTOBER 1-6, 1963
1.E2
1.E1
1.E0
1.E-1
1.E-2
1.E-3
M_2
.11 Open Mode Kugmallit Bay
.18 1/4 Resonant Wave Length
.2
.28 Closed Mode Kugmallit Bay
Shelf Mode (Herschel-Bathurst Shelf)
Pumping Mode
Closed Mode of Harbour
JANUARY 4-8, 1974
1.E1
1.E0
1.E-1
1.E-2
1.E-3
1.E-4
M_2
.125 Open Mode Kugmallit Bay
.18 1/4 Resonant Wave Length
M_6
Shelf Mode
Pumping Mode
0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00

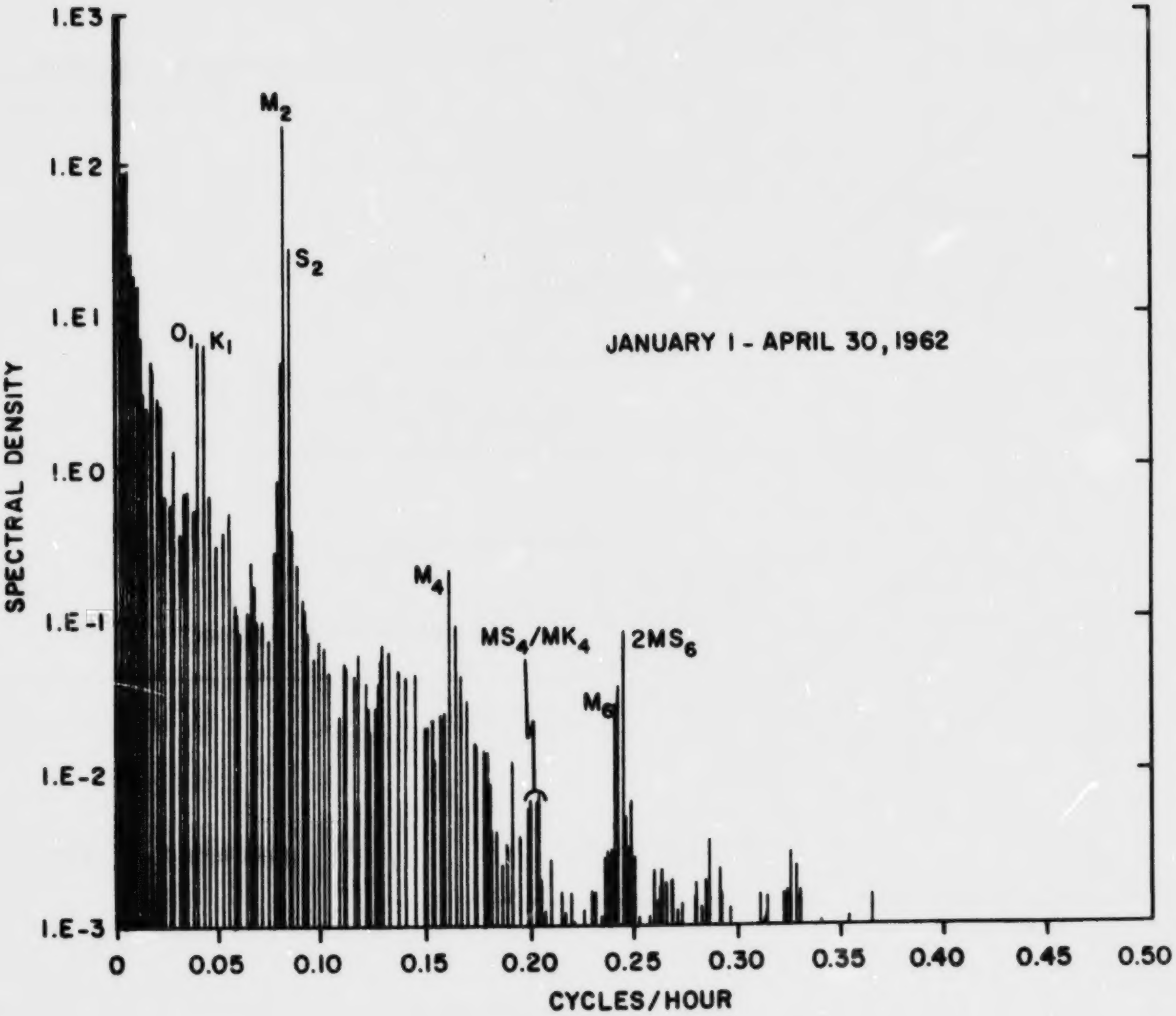


Figure 9-Spectra for ice cover & ice free periods 1962

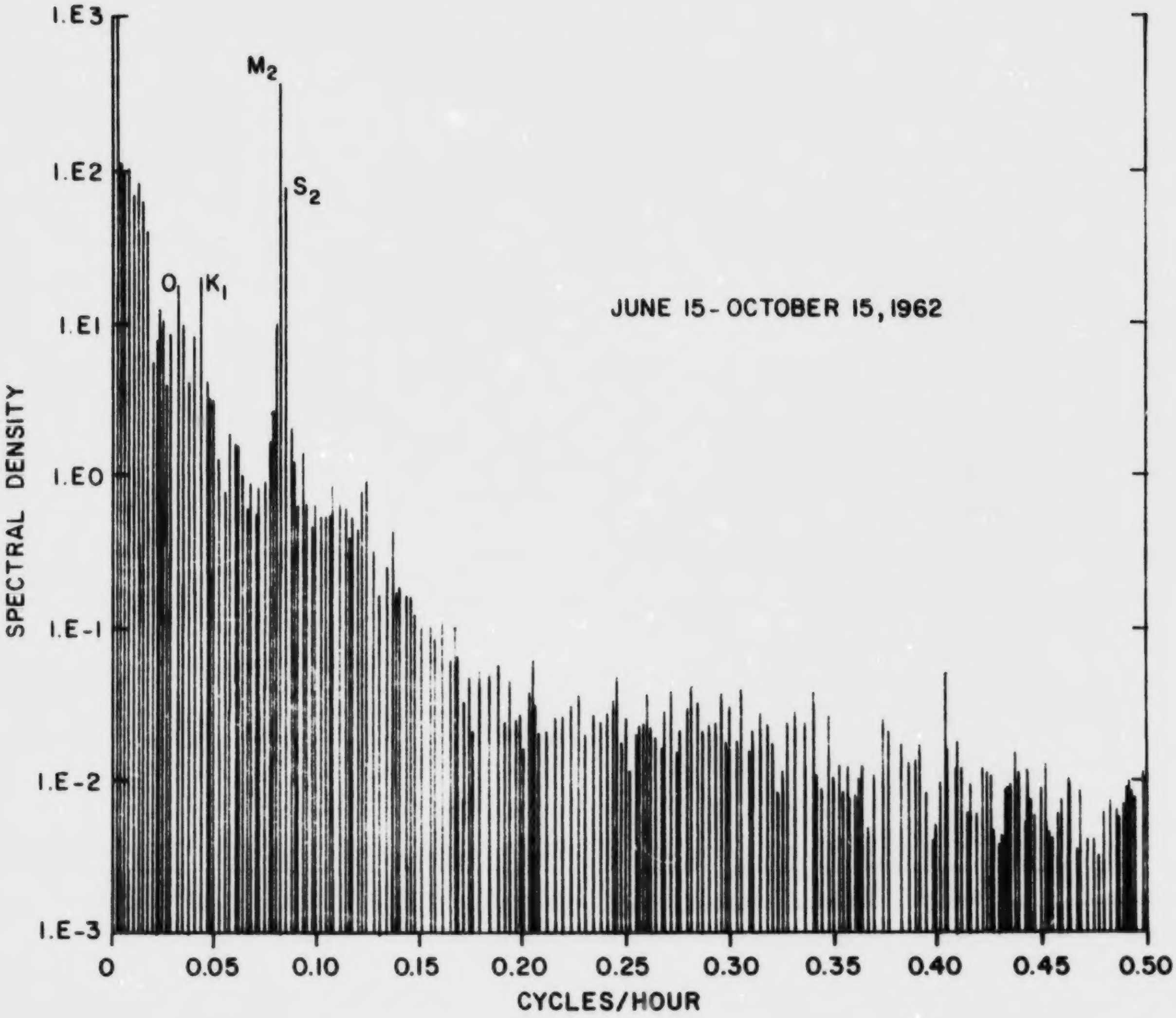


Figure 10-Spectra for ice cover & ice free periods 1962

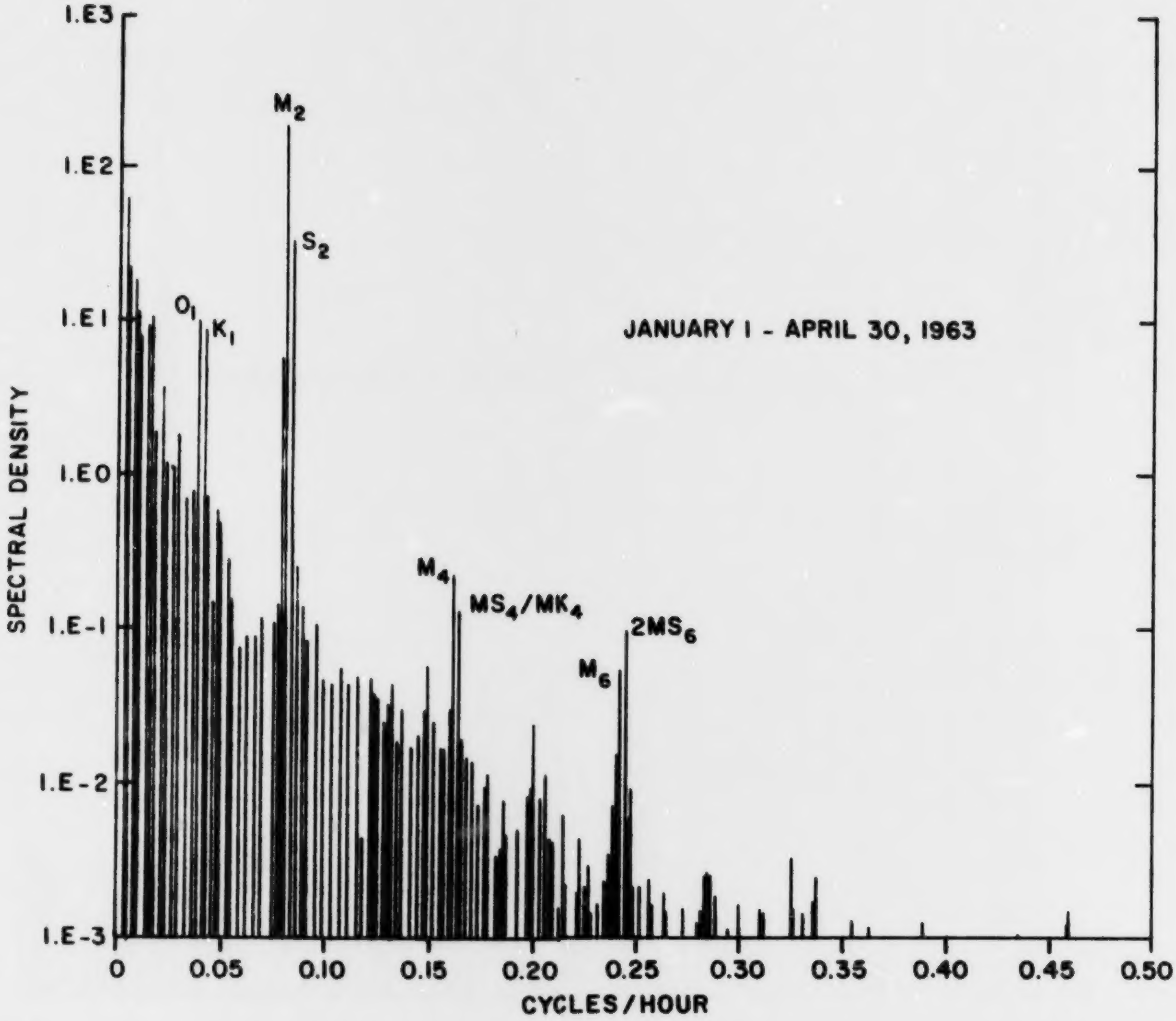


Figure 11-Spectra for ice cover & ice free periods 1963

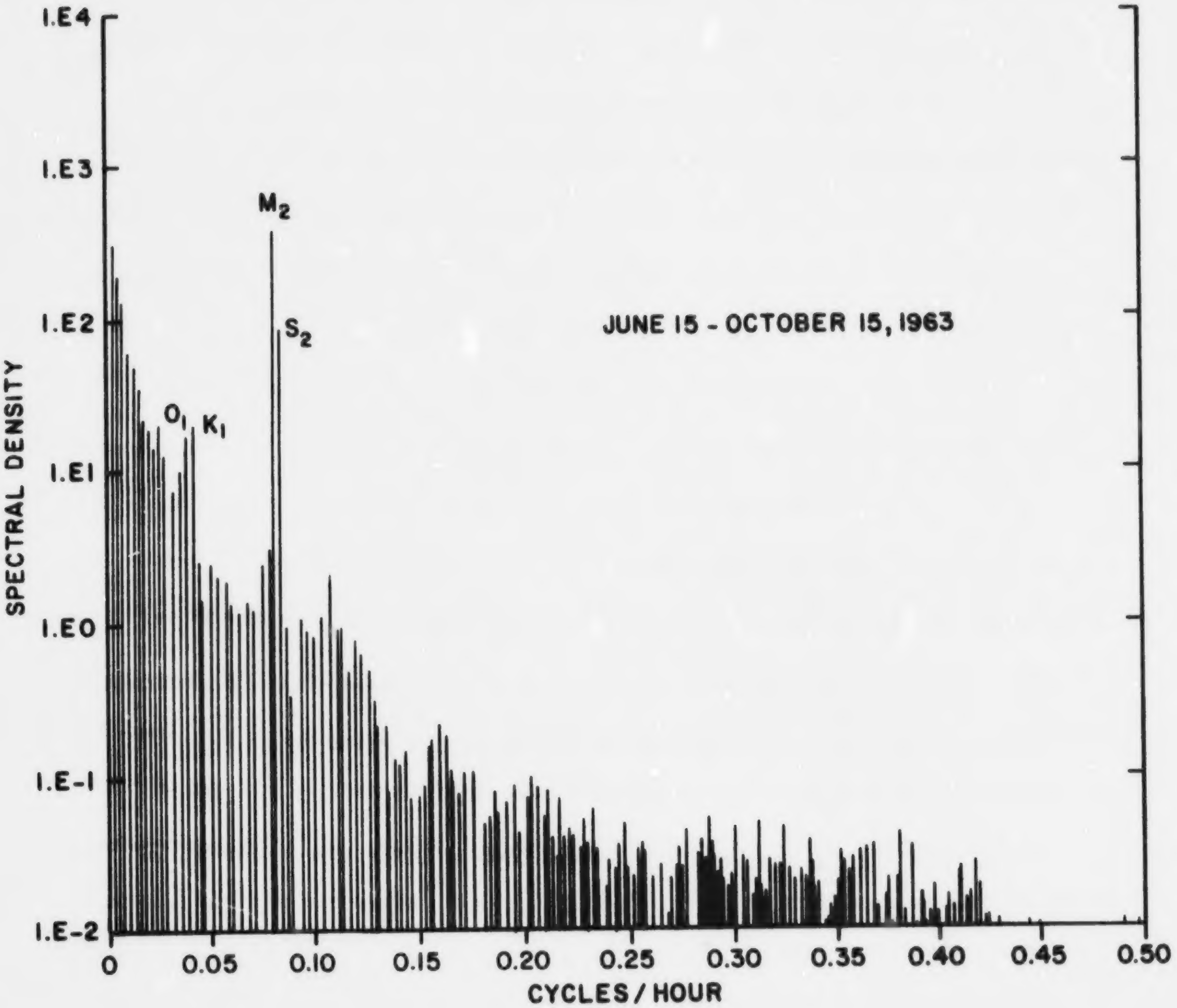


Figure 12-Spectra for ice cover & ice free periods 1963

4. Computation of the Free Oscillations

In this section estimates will be provided for the following resonant oscillations: one-quarter resonant wavelength of the Herschel-Bathurst Shelf, the fundamental mode edge wave on the shelf, the longitudinal and transverse modes of Kugmallit Bay, the modes of the Amundsen Gulf and the fundamental mode and Helmholtz mode of Tuktoyaktuk Harbour. We will start with the shelf.

The one-quarter resonant wavelength frequency is equal to 0.18 cph as computed from

$$\frac{\sqrt{gH}}{4B}$$

H = average depth of water = 50 m

B = Average width of the shelf = 108 km

g = acceleration due to gravity = 980 cm.sec^{-2}

An atmospheric distrubance travelling with a speed U would generate a fundamental edge wave mode whose frequency is given by

$\left(\frac{gs}{U} - f\right)2\Pi$, where the bottom slope s is of the order of 10^{-3} and the Coriolis parameter $f \sim 1.37 \times 10^{-4}\ \text{sec}^{-1}$. The computed edge wave mode frequency is 0.45 cph. For four disturbances in 1961, Hunkins (1964) gave values of U ranging from 6 to 15 $\text{m}\cdot\text{sec}^{-1}$. These values give an edge wave frequency of 0.64 to 0.45 cph. The 15 $\text{m}\cdot\text{sec}^{-1}$ value for U used above is based on the observation by Schafer (1966) that the storm of October 1963 travelled 150 km in three hours near Point Barrow.

The open (longitudinal) mode of Kugmallit Bay during ice cover may have a frequency which lies in the semi-diurnal band. The closed (transverse) mode of this bay appears to have a frequency of about 0.3 cph.

The frequency of the open mode during the absence of ice cover is about 0.12 cph, after applying a mouth correction (Defant, 1961).

For the Amundsen Gulf, the length was taken as 556 km and an average depth of 200 m. From the Merian formula, the frequency for the non-rotating case was estimated to be 0.073 cph (13.6 hours period). Rotation (Rao, 1966) would increase the frequency to 0.07 cph, which is quite close to the semidiurnal period.

For the harbour the frequency of the fundamental mode for the closed case is estimated to be about 1.0 cph in the absence of ice cover, and also in the absence of a surge. As noted above, ice cover reduces the water depth, and a positive storm surge increases the water depth. With ice cover and no surge, the frequency of the closed mode is estimated to be 0.9 cph; and without ice cover but with surge the frequency is 1.1 cph.

Helmholtz resonance basically represents the balance between the kinetic energy of the water flowing in through a narrow connecting channel, and the potential energy from the rise in the mean water level within the harbour. It is an additional gravitational mode of substantially longer period than the fundamental free oscillation. Let L_1 and L_2 be the lengths of the western and eastern entrances and s_1 and s_2 their areas of cross section. Then the frequency of the Helmholtz mode is given by

$$\sqrt{\frac{g}{A}}\left\{\frac{s_1}{L_1}+\frac{s_2}{L_2}\right\}^{\frac{1}{2}} \text{radians}\cdot\text{sec}^{-1}:$$

Table 1 lists the frequencies of the various modes estimated above.

TABLE 1

Frequencies (cph) of the various modes.

Mode	Ice-Free	Ice Cover
Herschel-Bathurst Shelf		
i) ¼ resonant wave length	0.18	0.18
ii) fundamental mode edge wave	0.45	0.45
Kugmallit Bay		
i) open, longitudinal	0.12	0.087
ii) closed, transverse	0.3	not seen
Tuktoyaktuk Harbour		
i) closed case (1st mode)	1.0	0.9
ii) Helmholtz mode	0.6 to 0.7	unknown

Table 2 lists the periods of the important tidal constituents that are examined in this study.

TABLE 2

Important tidal constituents considered in this study

Constituent	Type	Period (Hours)
M_2	semi-diurnal	12.42
S_2	"	12.00
N_2	"	12.66
O_1	diurnal	25.82
K_1	"	23.94
M_4	shallow water constituent	6.25
M_6	"	4.17

5. Influence of Ice Cover

The following results were deduced from the various spectra as shown in Figures 4 to 12. There is considerable noise in the tidal data in summer, and the noise is considerably reduced during ice cover. Periods of reduced noise in summer appear to be correlated with easterly and offshore winds. It is concluded that the input of noise mainly occurs over and inshore of the shelf. It seems likely that the reduction of noise in winter is characteristic of fast-ice areas.

The main tidal constituents are influenced by ice cover (Table 3); in particular, their amplitudes are greater during the period of open water. The change in amplitudes of the main constituents in part is due to the increased partition of energy to the shallow water constituents during ice cover periods. Generally in the tidal data for the harbour peaks corresponding to the following constituents can be seen: O_1, K_1, M_2, S_2, M_4, MS_4/MK_4, $M_6$and SMS_6.

TABLE 3

Summary of the influence of ice cover on various tidal constituents.

Tidal Constituent	Frequency cph	Amplitude (ft) Yearly	Amplitude (ft) Winter 1962	Amplitude (ft) Summer 1962	Amplitude (ft) Winter 1963	Amplitude (ft) Summer 1963	Energy ratio $\frac{\text{winter}}{\text{summer}}$ for 1962	Energy ratio $\frac{\text{winter}}{\text{summer}}$ for 1963
M_2	0.0805	0.420	0.360	0.533	0.370	0.525	0.47	0.51
S_2	0.0833	0.176	0.145	0.243	0.158	0.250	0.36	0.41
K_1	0.0418	0.116	0.070	0.123	0.080	0.123	0.33	0.43
O_1	0.0387	0.089	0.071	0.078	0.086	0.112	0.84	0.60
M_4	0.1610	0.006	0.012	0.006	0.013	0.009	3.75	2.06
MS_4/MK_4	0.1639	0.003	0.008	0.005	0.010	0.004	2.91	7.82
M_6	0.2415	0.002	0.005	0.002	0.006	0.003	6.33	3.79
$2MS_6$	0.2444	0.003	0.008	0.004	0.008	0.005	3.45	2.77

Shallow water constituents, such as M_4, M_6, etc. are always present in any basin to a certain extent. The constituents M_4 (0.16 cph) and M_6 (0.24 cph) can be prominent during the period of winter ice cover. This correlation with ice cover suggests that either the general decrease of depth due to ice (particularly in Kugmallit Bay) or the increase in friction between the landfast ice and water leads to the shallow water constituents. A display of the spectra in overlapping segments of 15 days (not shown here) shows that M_4 gradually increased in amplitude until June. Then it is not seen until the winter ice cover is in place. On the other hand, M_6 did not increase over the winter period, but disappeared from the record with the breakup of ice in Kugmallit Bay. The implication is that, the increase of friction due to ice is important for M_6, but that ice thickness influences M_4 (i.e. depth decreases with increasing thickness of ice).

6. Conclusions

Ice cover in Tuktoyaktuk Harbour has significant influence on the free oscillations and tides. Whereas the semi-diurnal and diurnal tidal constituents are generally weakened during ice cover, the shallow water constituents are stronger during winter ice cover.

Acknowledgements

We thank Ms. Dorothy Wonnacott for typing the manuscript and Ms. Coralie Wallace for drafting the diagrams.

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CHALK RIVER: A NATIONAL TECHNOLOGICAL RESOURCE

by

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ABSTRACT

For almost 40 years the Chalk River Laboratories of Atomic Energy of Canada Limited Research Company have played a predominant research and development role in support of the Canadian nuclear power program. The technological success and maturity of this industry coupled with the changing economic climate has resulted in a diversification of the laboratories activities. This includes, but is not limited to, wide ranging R&D projects in support of private industry, industrial associations or government agencies.

This paper reviews Chalk River's skills and resources and areas of expertise which, coupled with the common priority placed on safety, low maintenance and high reliability, may complement the needs of the offshore oil and gas industry. In particular, techniques in environmental science, non-destructive testing, materials and mechanical equipment development, corrosion science, specialty pumps and valves, instrument development and computer process control will be highlighted.

Reference will also be made to the development of SLOWPOKE 3, a small nuclear reactor for low temperature (100°C) space heating, and its relevance to remote Arctic communities.

1.0 INTRODUCTION

For almost 40 years the Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited Research Company have played a major research and development role in support of the Canadian nuclear power program. Close co-operation with industry and Ontario Hydro has resulted in CANDU - a nuclear reactor which consistently leads the world in reliability and performance. This outstanding success has also created a less visible, but essential, multi-disciplinary team of engineers and scientists with all the skills and resources necessary to sustain such an advanced technology.

As the industry has matured the laboratories have begun to diversify their activities beyond the traditional 100% federally funded support of nuclear energy. This has involved the marketing and exploitation of Chalk River's know-how on a world wide basis to both nuclear and non-nuclear customers. Today, contract research and development, together with sales of products and services, accounts for about 25% of a $130 million annual budget.

This paper offers a brief introduction to Chalk River and, in particular, highlights areas of on-going research and development which may have particular relevance to hydrocarbon production in the North.

2.0 CHALK RIVER NUCLEAR LABORATORIES

Chalk River Nuclear Laboratories represent the major research and development organisation of Atomic Energy of Canada Limited (AECL), a federally supported Crown Corporation. As part of the AECL corporate structure the laboratories are in turn backed by a comparable, but smaller research facility at the Whiteshell Nuclear Research Establishment in Pinawa, Manitoba; a Radiochemical Company which has established world-wide markets for radioactive isotopes, medical therapy units, Cobalt-60 sterilisation and food preservation irradiators, and by CANDU Operations which, along with its full scale engineering test laboratory, is responsible for design and engineering, heavy water production and the marketing and after sales service of CANDU reactors. Total AECL staff is 7,400 of whom close to 50% are associated with research and development.

Located on the Ottawa River, 200 km north west of Ottawa, Chalk River itself employs some 2,400 people including about 500 professional scientists and engineers, 500 technicians and technologists, 900 highly skilled machinists, welders, instrument mechanics and other trades people and 500 support staff. The laboratories have seven major research divisions divided into 29 individual branches covering the whole spectrum of pure and applied sciences. These in turn are supported by other major divisions including design and engineering, maintenance and construction, general and administrative services and commercial operations.

Chalk River is well equipped with modern analytical and engineering facilities and its staff well versed in the transfer of technology to Canadian industry. Major strengths include the ability to quickly assemble multi-disciplinary teams of specialists, thorough familiarity with safety and reliability analyses, and the management of large, high quality, science and engineering projects.

Specific areas of on-going research and development with potential spin-off or application in the north are briefly discussed below.

3.0 ENVIRONMENTAL RESEARCH

Because of the obvious need to safely manage and understand the effects of planned or inadvertent release of radioactive materials to the environment, a large body of expertise is available in the field of environmental research. Since radioactive isotopes are easily detected and analysed at low concentrations they represent a very convenient self indicating tracer for monitoring and modelling the transport and dispersion of contaminants in the geosphere and biosphere. Techniques and knowledge developed in the nuclear industry relating, for example, to ground water and atmospheric transport, uptake by flora and fauna, computer modelling and associated analytical techniques, may all have potential application to regional environmental studies in the North and be complementary to existing programs.

Tracers have, for example, been used to monitor and optimize the placement of sediments from dredging operations, to monitor the effectiveness of oil-spill dispersants; for flow measurement and meter calibration and the detection of leaks in heat exchangers and other equipment (Charlton, Heslop and Johnson, 1982), and to determine inter-well communication in tar sands deposits. They may also be applicable as a tool for the remote sensing of contaminants on or below ice.

4.0 NON-DESTRUCTIVE TESTING (NDT) AND TOMOGRAPHY

Because of its great emphasis on reliability and safety, the nuclear industry has played a major part in the application of NDT techniques to detect abnormalities such as cracks, voids, corrosion and welding defects in critical components. Chalk River operates

Canada's most comprehensive NDT facilities with a highly experienced staff specialising in the design and development of new procedures for field applications, evaluation or modification of existing procedures for special environments and general consulting.

The group has experience with all major NDT techniques and particular expertise in the use of eddy current, ultrasonics and remotely controlled inspection systems. Canadian NDE Technology Limited are licensees for the manufacture of eddy-current saturation probes for testing a range of ferromagnetic heat-exchanger tubes.

With respect to offshore structures we perceive a need for Canadian input in the development of on-line methods for monitoring structural integrity for minimising operator (i.e. diver) dependent involvement and interpretation. Current practice and needs, to which Chalk River could contribute, have been reviewed by (Harris, 1983) and (Klimo, 1980).

Recent applications of tomography offer exciting possibilities. Tomography is a computer assisted multi-scan technique for generating cross-sectional density maps (Swindell and Barrett, 1977). This technique was pioneered in medicine using X-rays, and is capable of resolving abnormalities with millimeter resolution. Figure 1(a) shows, for example, a computer assisted tomography (CAT) cross sectional scan of a log using the Kingston General Hospital X-ray CAT scanner. A corresponding photograph of the same plane is shown in Figure 1(b). By the time the log was sawn, and the photograph taken, several weeks had elapsed and cracks had appeared in the log. These were absent when the CAT scan was performed but otherwise the two images show the same features and illustrate the excellent resolution which can be obtained (Tonner and Lupton, 1982).

By using more penetrating γ-radiation the method can be applied to examine more dense materials such as steel and concrete for imperfections in critical areas. Figures 2 and 3 illustrate examples of work underway in γ-tomography at Chalk River but obtained with far fewer scans and hence less overall resolution.

5.0 MATERIALS AND MECHANICAL EQUIPMENT DEVELOPMENT

This heading covers a very broad spectrum ranging from basic R&D on new materials through safety and reliability analyses to the design and fabrication of specialised remote handling and tooling devices for the inspection, maintenance and repair of equipment in otherwise inacessible or hostile environments.

Figure 4 shows, for example, Chalk River's version of a " space arm" which was used to remotely locate and repair highly radioactive leaking tubes at the Douglas Point nuclear generating station in Ontario.

When "off-the-shelf" equipment failed to meet the nuclear industry's need for high reliability and low leak rates in high temperature (300°C) and pressurised 10 MPa (1450 psi) heat transfer systems, Chalk River pioneered the development of long life static and rotating pump seals and live-loaded valves. Rotating pump seals with a five year life are now achievable, a five fold improvement over earlier standard designs. Along with improved valve stem seals and bellows valves these are giving rich dividends in terms of low maintenance and downtime. (Ross-Ross and Metcalfe, 1983)

Similarly our understanding of friction, lubrication and wear allows the choice of suitable materials for moving parts such as pistons, slides, threads, ball bearings etc., to be chosen with confidence at the design stage. More could be achieved if the benefits of the lead established in nuclear seal technology could be transferred directly to other Canadian industry.

In total, reliability and systems maintainability analyses are an essential component in the design of nuclear systems. This is key to minimising unplanned shutdowns with their inevitable effects of lower capacity factors and higher production costs. We believe there is considerable scope for application of this know-how in the hydrocarbon industry.

6.0 CORROSION SCIENCE

Corrosion related problems are expensive and estimated to amount to over $5 billion annually in Canada alone. Recent U.S. studies suggest that approximately 25% of these costs could be avoided if existing technology was utilized. Proper selection of materials and adequate corrosion protection methods are part of Chalk River's on-going programs both in contract R&D and nuclear related heat transport systems. Extensive testing and surface analysis facilities are available to study a wide variety of materials and environments including, H_2S, CO_2, saline and caustic solutions. Chemical cleaning methods for specific applications have also been developed and marketed with considerable commercial success via a licensing agreement with London Nuclear Ltd.

7.0 INSTRUMENT DEVELOPMENT

Chalk River's Electronics, Instrumentation and Control Division embraces a variety of skills which range from the conceptual design, fabrication and testing of specific instrumentation packages to sophisticated data acquisition and computer process control networks.

For example, using hybrid micro-electronics we have developed a microprocessor controlled miniaturised multi-purpose down-hole probe for the measurement of up to 8 independent variables such as temperature, pressure, conductivity, pH, etc.

A 5 cm diameter instrument package (Figure 5) was required for AECL's underground waste management program and was achieved by miniaturising existing technology with the full cooperation of an industrial partner, Guildline Instruments Ltd. The new, and more versatile, probe may well be applicable for down-hole logging in hydrocarbon exploration and oceanography.

In data communications and process control we have developed a versatile local-area network that uses standard co-axial cable TV hardware as the transmission medium. This patented system allows guaranteed access, interfacing and control of multi-vendor peripheral equipment such as sensors, terminals, word processors, microprocessors and computers (Capel, A.C., 1982). This is currently being evaluated in co-operation with a potential licensee and could well be ideally suited for installation in off-shore oil rigs. It is currently being installed at Chalk River for data acquisition and control of the two research reactors. The entire network can accommodate up to 100 independent connections.

8.0 SLOWPOKE 3

SLOWPOKE 3 is a safe low power self controlling nuclear reactor with characteristics which could well meet the needs of remote Arctic communities (Hilborn, and Glen, 1981).

The concept is based on 12 years proven design and operating experience with six 20 kW_{th} SLOWPOKE 2 reactors currently being used in universities and research institutions across Canada. The new SLOWPOKE 3 is an uprated version of these predecessors and is intended to operate at power levels of 2 MW_{th}.

Figure 6 shows a conceptual picture of the reactor, the core of which is contained near the bottom of a 9 m deep pool filled with water. The heat from the nuclear reaction maintains the pool at 80°C and is transported by natural convection to heat exchangers and then subsequently to the buildings for space heating. Based on fundamental physics principles the reactor is inherently safe and will operate unattended for two heating seasons before needing to be refuelled. Designs which will also allow the reactor to produce electricity are also being considered.

Preliminary estimates for heating costs compare favorably with electricity and oil and a decision whether or not to proceed with the construction of a prototype reactor is expected later this year.

9.0 INTERACTION WITH INDUSTRY

It should be emphasized that in all the above or other areas Chalk River does not intend to compete with the private sector. Rather it is our policy to complement the activities of other industries by providing them access to a broad multidisciplinary R&D base which can enhance their own products and services. This is commonly done by acting in a sub-contractual role.

Our own "in-house" technology is, wherever practicable, transferred to Canadian industry through licensing agreements in which we liaise closely with the licensee to ensure the technology remains up-to-date and marketable. Alternatives, such as the formation of joint ventures, where both parties can share the risks and benefits are also seriously considered.

The intent is that Chalk River can continue to do what it does best, R&D, but, by cooperating with industry, can still share in the benefits which accrue in the market place.

A very recent initiative involves Chalk River's participation, as the North American partner, in the supply of a Heat Transfer and Fluid Flow Service (HTFS). A model venture in technology transfer, HTFS provides an efficient mechanism through which advanced heat transfer and fluid flow technology is developed and shared by diverse industries worldwide.

HTFS conducts an applied research program on the design and operation of major heat exchange equipment such as shell and tube exchangers, air-cooled exchangers and furnaces, and problem areas such as two-phase flow maldistribution and tube vibration.

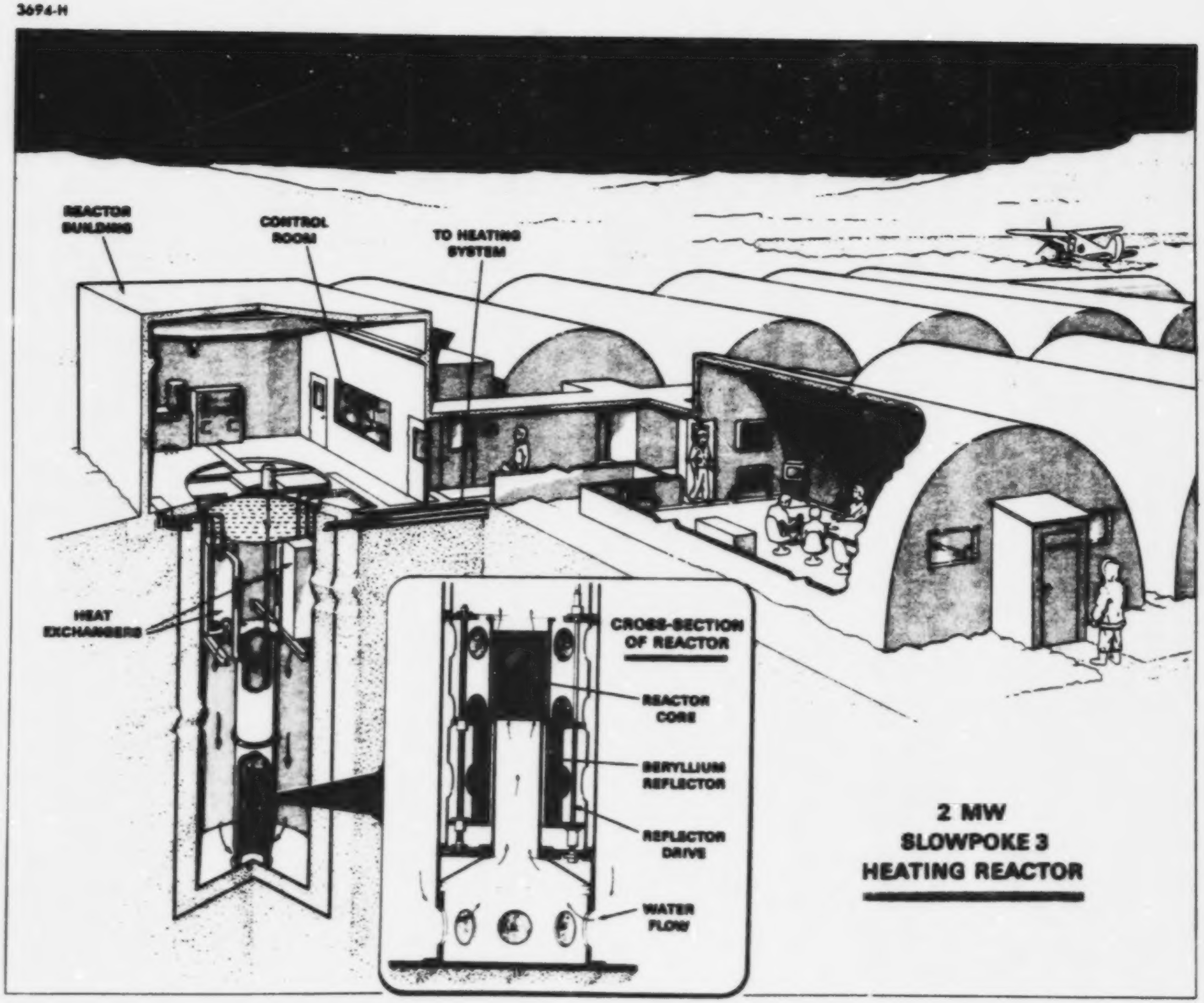
3694-H
REACTOR BUILDING
CONTROL ROOM
TO HEATING SYSTEM
HEAT EXCHANGERS
CROSS-SECTION OF REACTOR
REACTOR CORE
BERYLLIUM REFLECTOR
REFLECTOR DRIVE
WATER FLOW
2 MW
SLOWPOKE 3
HEATING REACTOR

FIGURE 6. ARTISTS IMPRESSION OF A 2 MW_{th} SLOWPOKE 3 HEATING REACTOR FOR ARCTIC COMMUNITIES.

Members participate in planning the program and receive the results through design manuals, computer codes, consultation by HTFS specialists, and a comprehensive information system.

Originally founded in 1968, and operated by two United Kingdom (U.K.) laboratories, the Harwell Laboratory of the Atomic Energy Authority and the National Engineering Laboratory of the Department of Industry, HTFS now has over 150 members in 20 countries worldwide.

The U.K. Department of Industry has provided continuing financial support to HTFS research. The Canadian government is supporting Chalk River's research program with a major grant from Energy, Mines and Resources Canada. Membership fees are used to finance the functions through which HTFS transforms the results of the research programs into computer codes and other design tools, and disseminates them to members.

For the oil and gas industries in particular, Chalk River has undertaken a variety of contracts including ultrasonic techniques for the sizing of defects in pipe welds, studies on CO_2 induced corrosion, γ-densitometry for the non-intrusive evaluation of two-phase flow in hydrocracking processes, investigation of on-line techniques for monitoring carbon/hydrogen ratios and oil/water compositions, γ-scanning of distillation columns to identify and correct process malfunctions, testing of column packings and flow meter calibrations.

In offshore or Arctic development we would welcome similar opportunities to work with the petroleum associations, the Canadian Ocean Industries Association and their research organisations such as the Canadian Offshore Oil Spill Research Association (COOSRA), the Arctic Marine Oil Spill Program (AMOP). Similarly we would be happy to respond to initiatives taken by the Canada Oil and Gas Lands Administration (COGLA) and priority areas for R&D identified by the Environmental Studies Revolving Funds (ESRF).

In conclusion we believe that substantial benefits to Canada can be realised by recognising that Chalk River does represent a significant national technological resource and then seeking ways to exploit it to everyones advantage. Cooperative arrangements with industry and/or government are not new to Chalk River. What is new is our desire to identify needs and see our skills and resources effectively utilised in a diversified way. We are confident this can help to develop safe and reliable solutions for some of the unique problems associated with the exploitation of our indigenous resources.

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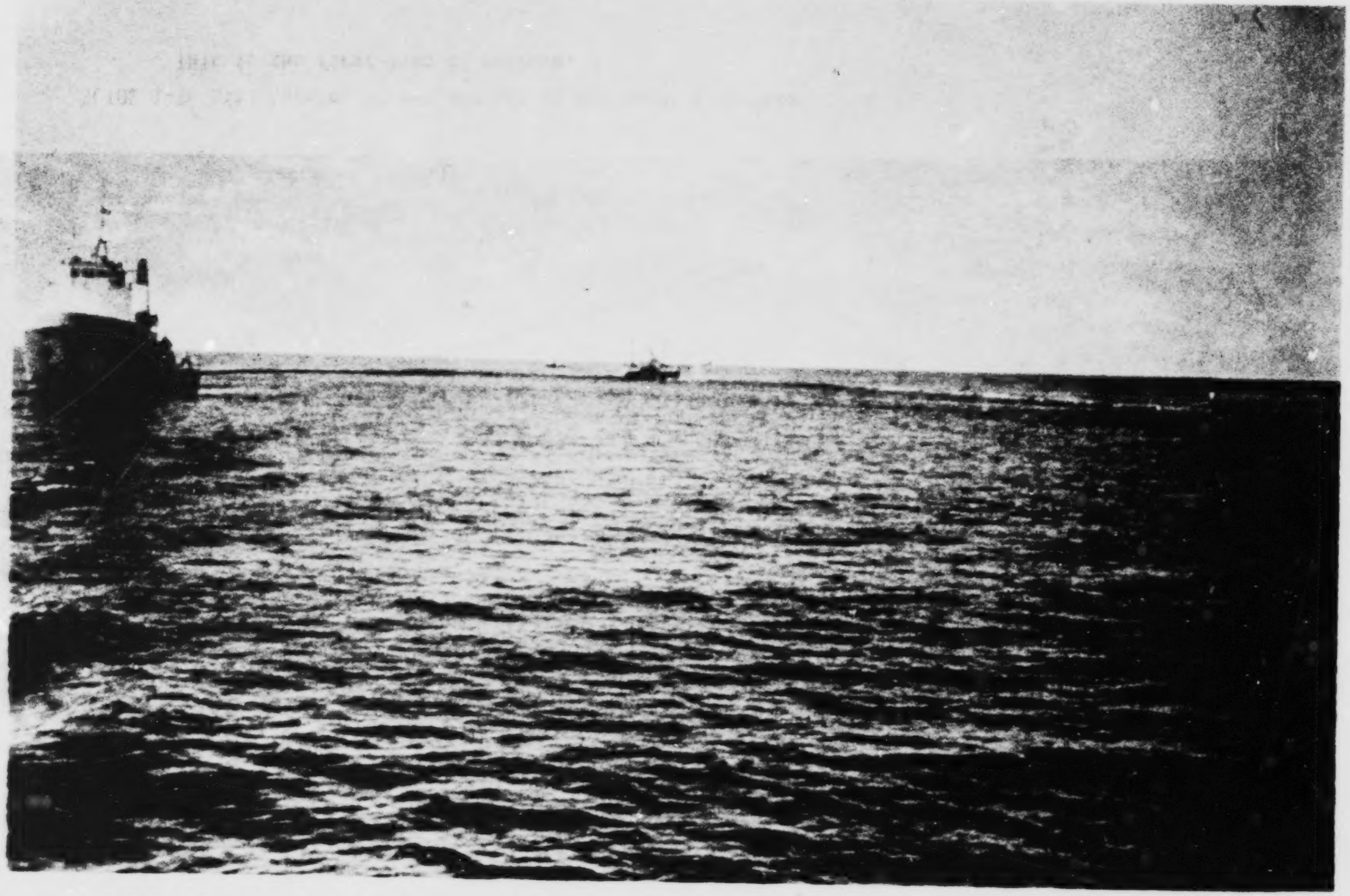
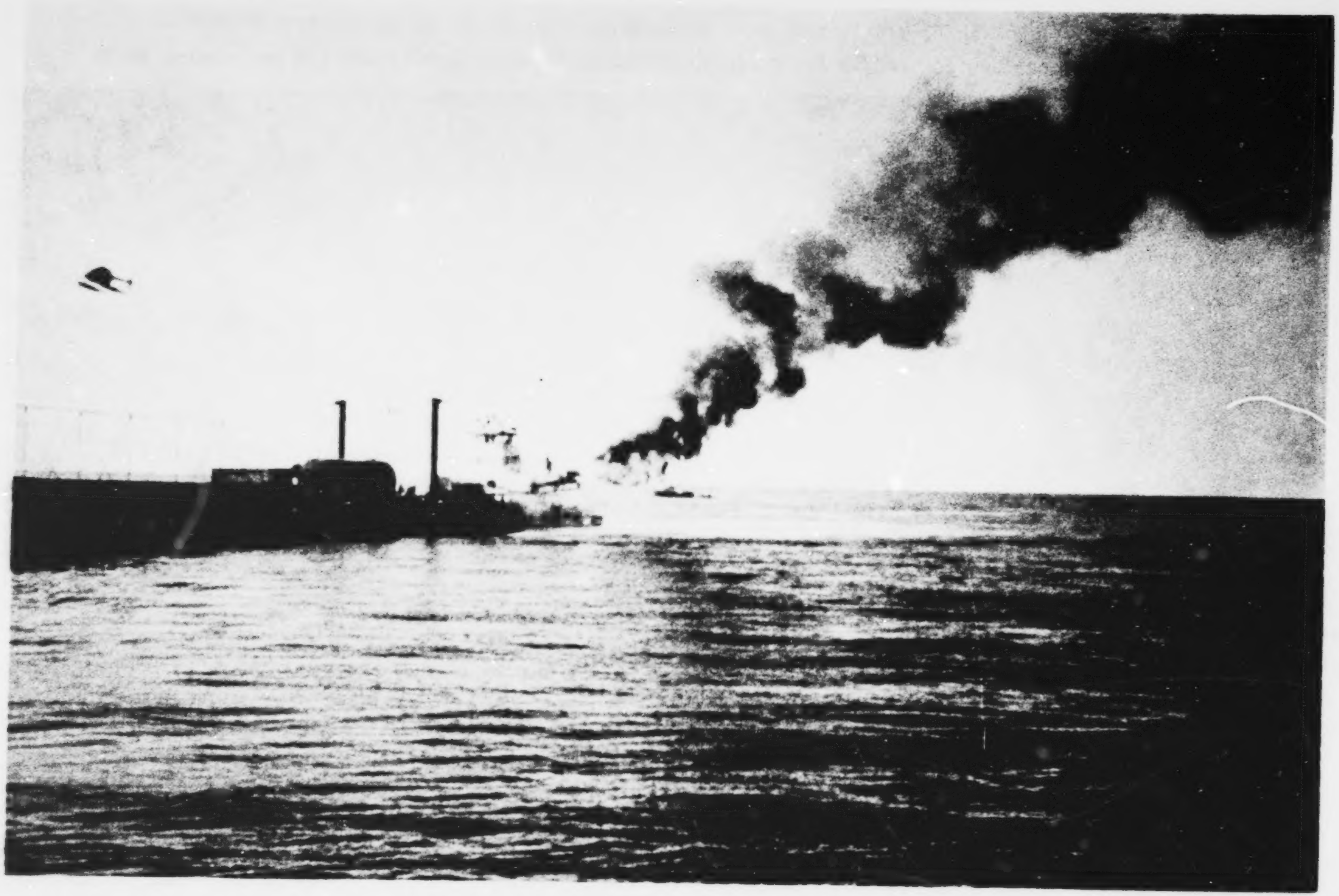
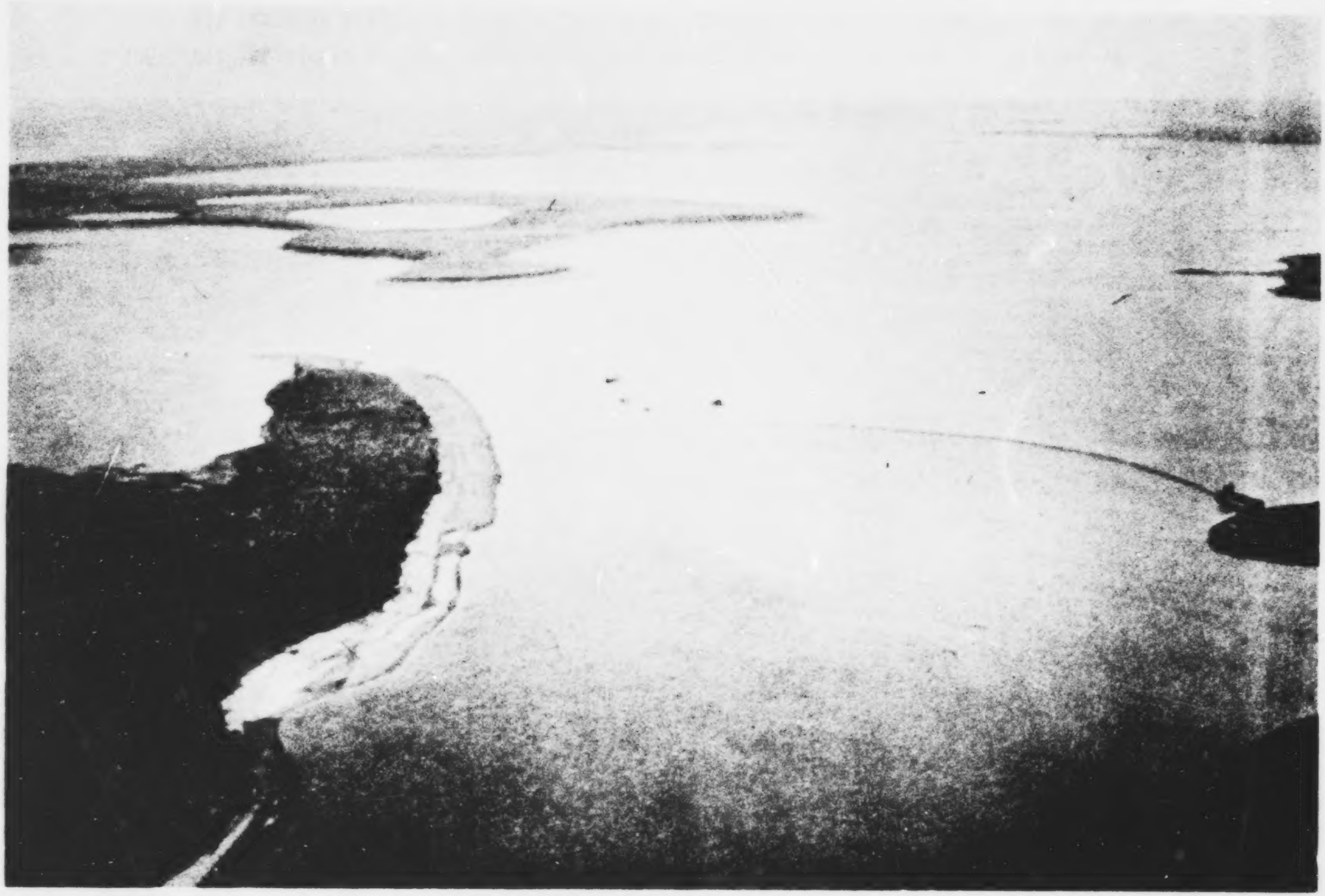
SLIDE 1-In situ burning of oil and gas at the water's surface.
This is the first line of defense.



SLIDE 2-The development of the containment boom. Oil will be funnelled to the back of the V-configuration where it will be recovered by the response barge(centre background).

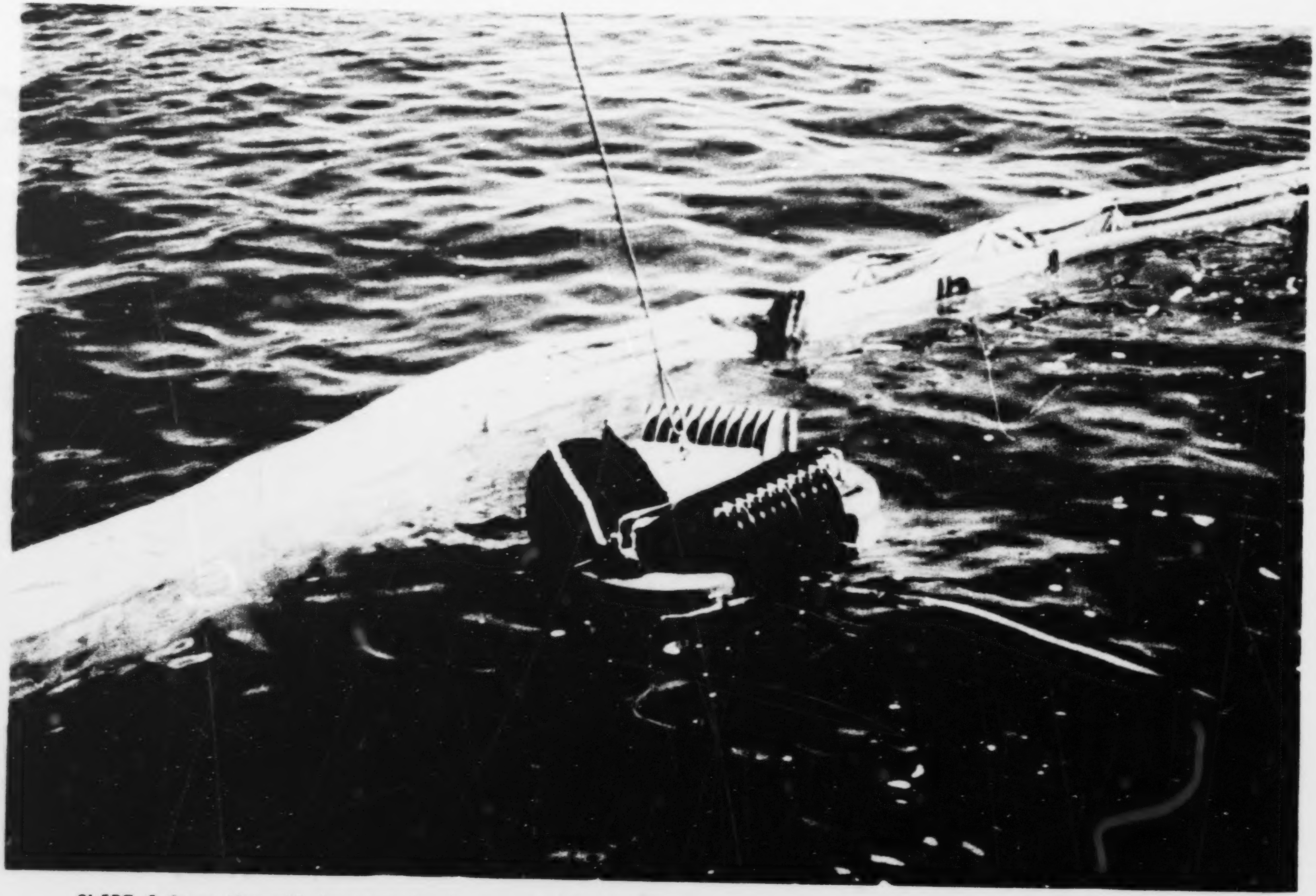


SLIDE 3-Oil is skimmed off the water and is disposed by a burner situated at the rear of oil response barge.

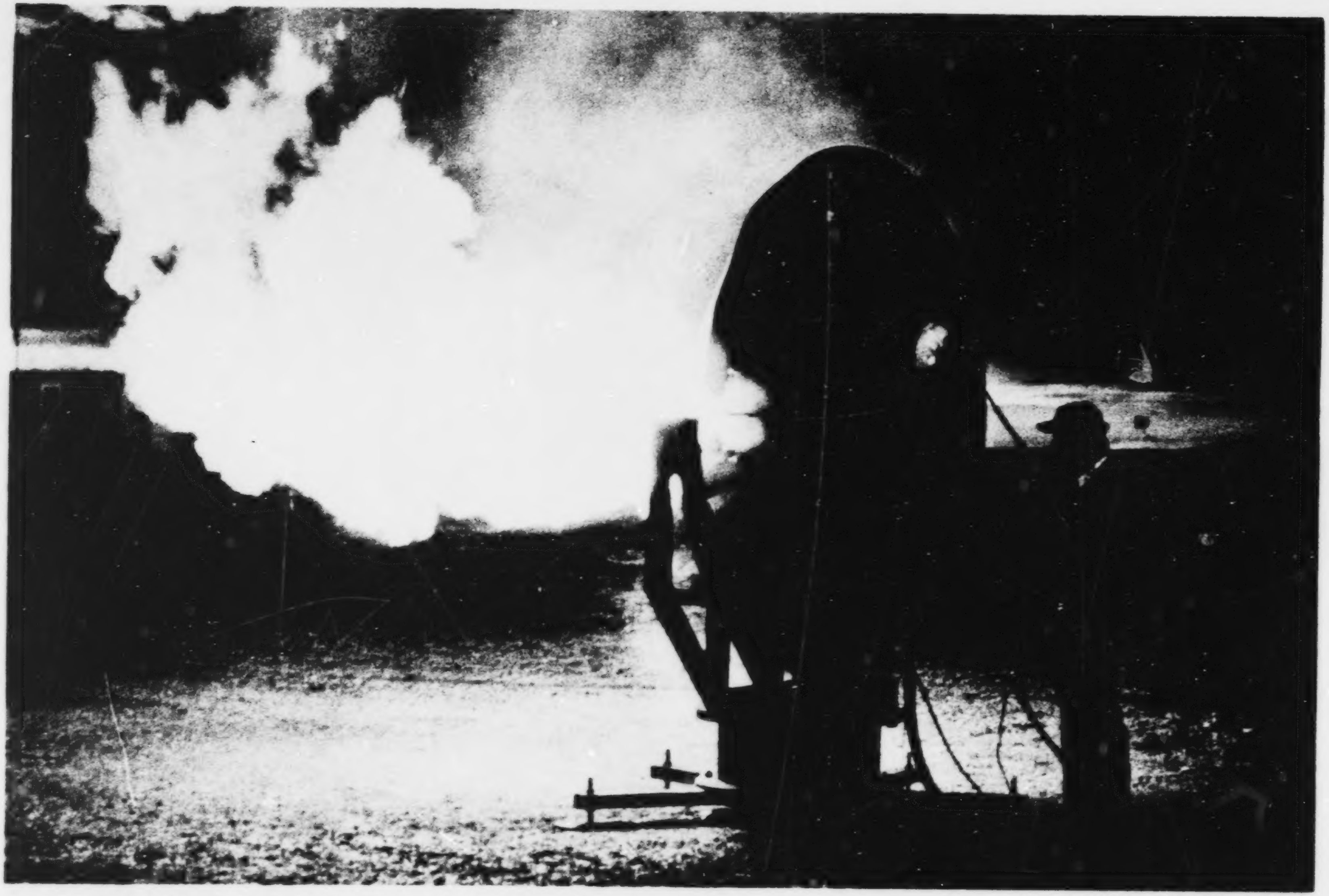


SLIDE 4-Here, an oil containment boom is stretched across a bay as part of the shoreline countermeasures which are further illustrated in slides 5, 6 & 7.

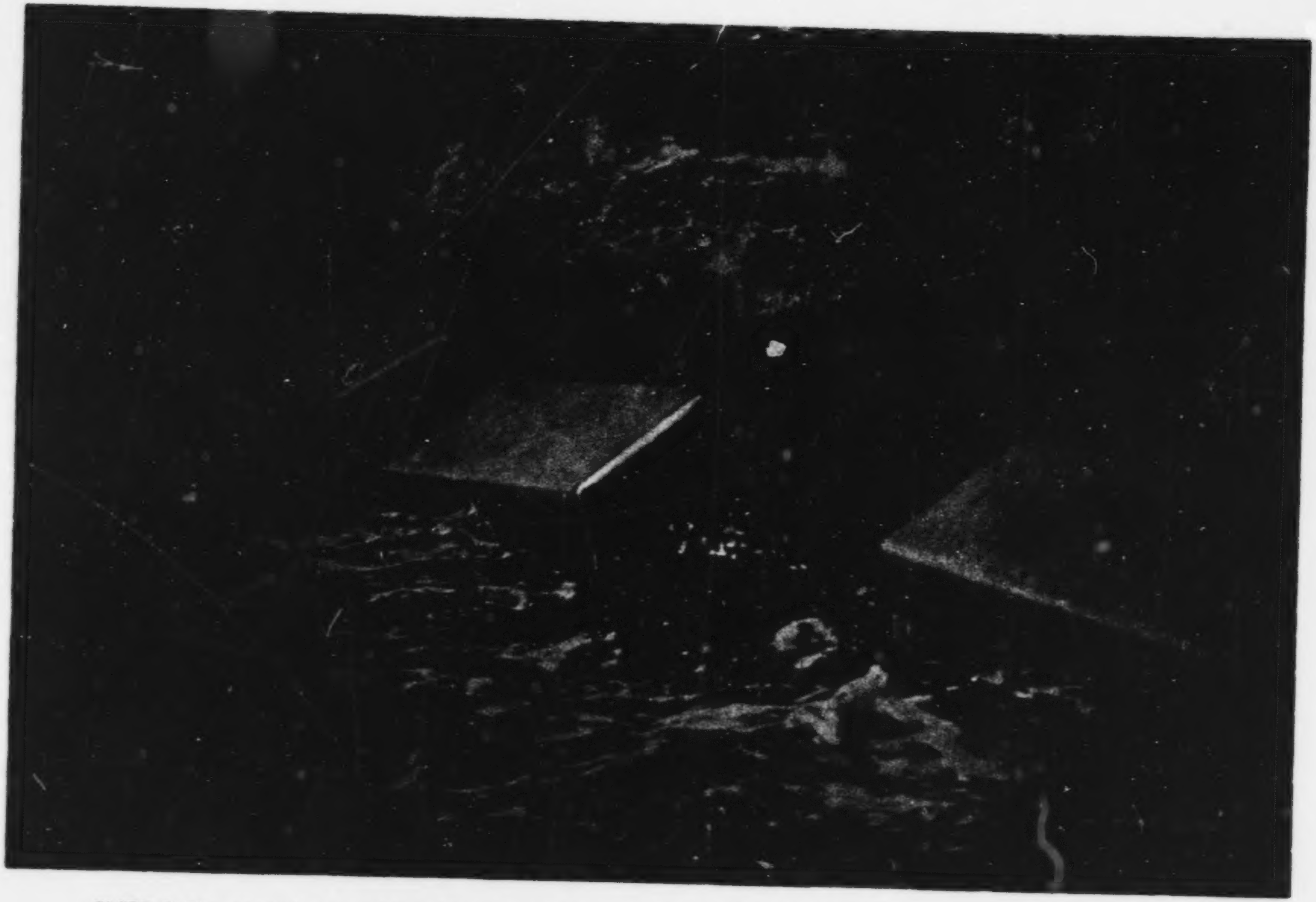
SLIDE 5-A skimmer is deployed to recover the oil.



SLIDE 6-Once the oil is contained, a portable burner can be deployed. This slide shows the collecting device and transport tubes that lead to the burner.

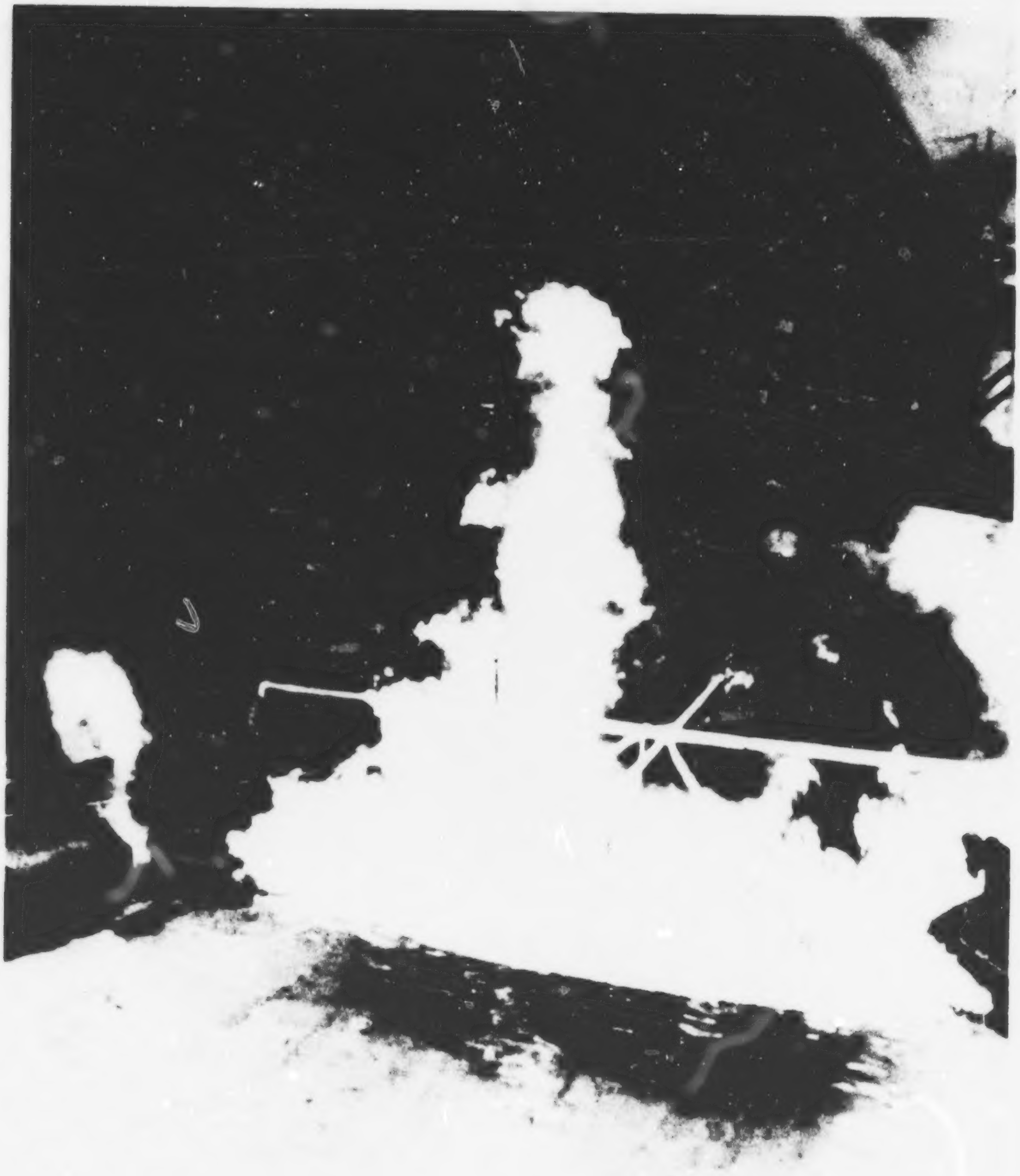


SLIDE 7-A rotary cup burner. The main transport tube from the collection device offshore can be seen leading to the centre portion of the burner.

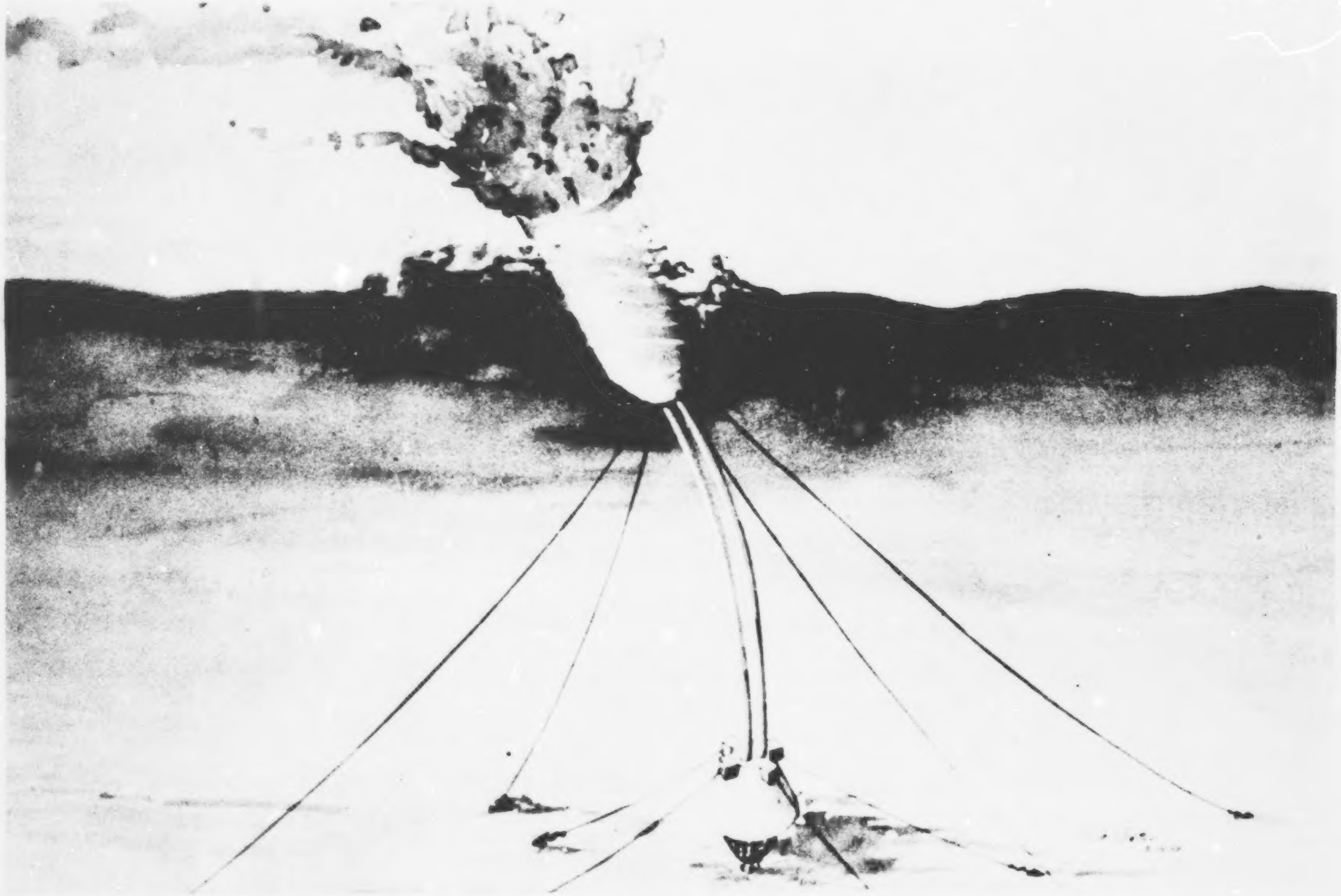


SLIDE 8-The second generation fire-proof boom--stainless steel model. The original concept consisted of oil drums joined together by fireproof material.

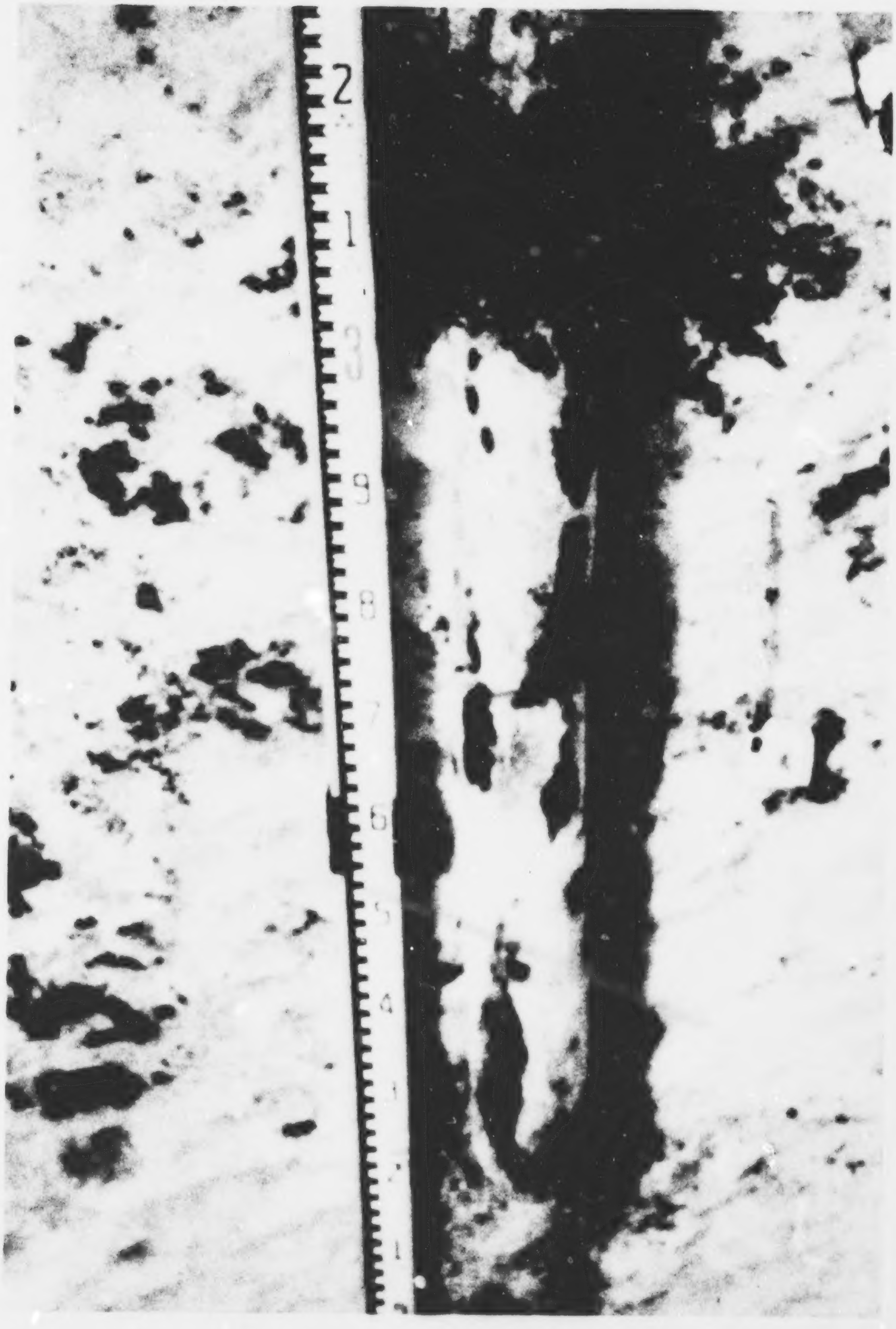
SLIDE 9-This and slide 10 show test tank trials of the stainless steel boom.
This particular slide shows the containment test.



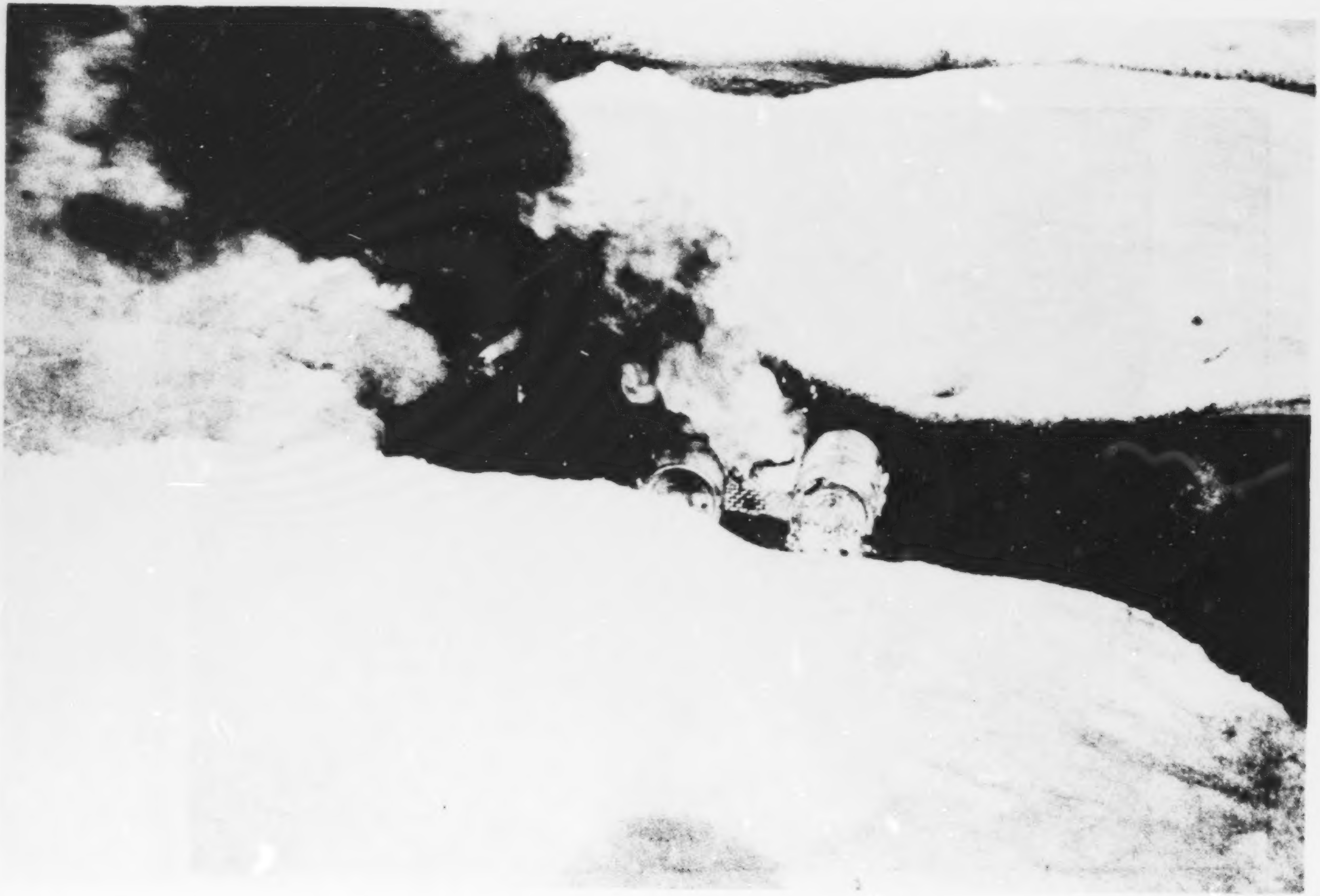
Slide 10- The burn test



SLIDE 11-An artist's drawing depicts the sub-sea containment concept presently under investigation.



SLIDE 12-Brine channel migration of oil through ice.



SLIDE 13-The air deployable igniter in its final form.

PHOTO 1 Dumping sea ice in test pit at East Dock in preparation for Tasks 1 and 2.

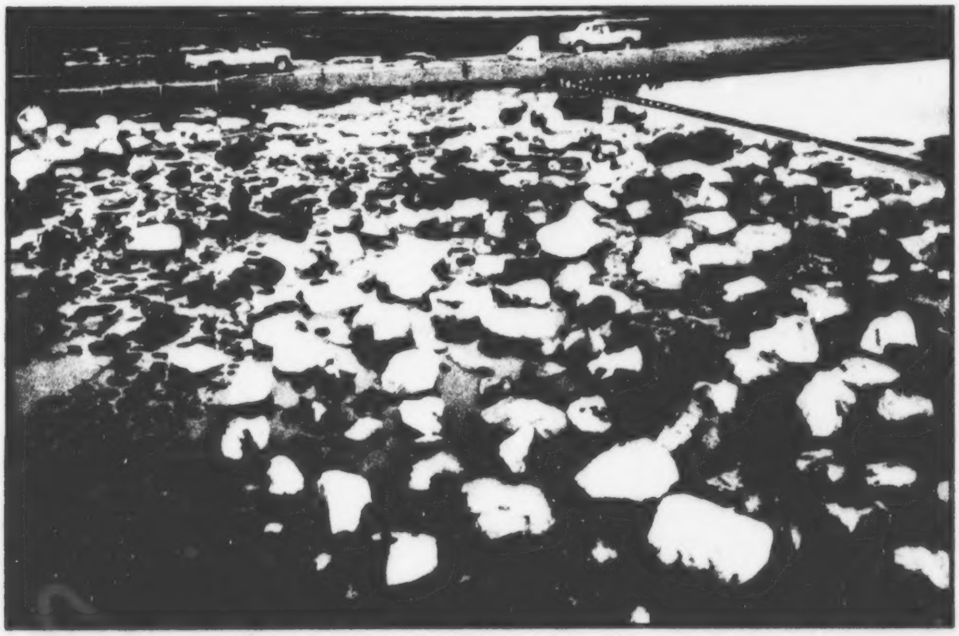


PHOTO 2 Grounded ice (3 to 5 oktas coverage) in test pit prior to Task 1, Tests 1 and 2.

PHOTO 3 Observation/oil discharge platform suspended over test pit for Task 1, Test 1.

PHOTO 4 Discharge of oil into pit during Task 1, Test 1.

PHOTO 5 Oil spreading among broken ice pieces prior to ignition during Task 1, Test 1.

PHOTO 6 Ignition of crude oil among grounded broken ice pieces during Task 1, Test 1.

PHOTO 7 Oil burning on water among broken ice pieces during Task 1, Test 1.

PHOTO 8 Cleanup of burn residue with sorbents following Task 1, Test 1.

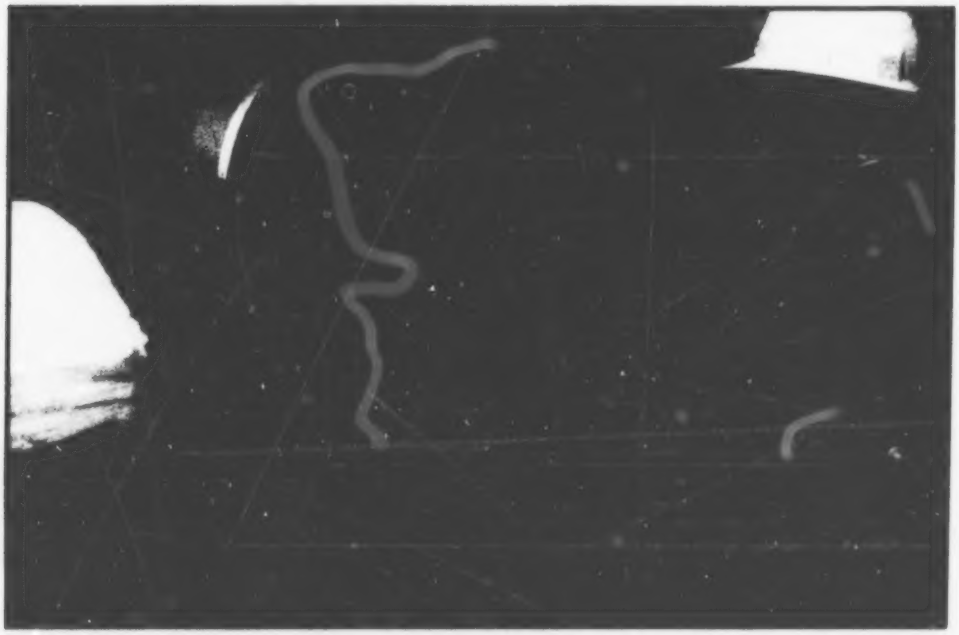


PHOTO 9 Weighing oil-soaked sorbents with residue from Task 1, Test 1 burn.

PHOTO 10 Discharge of oil into test pit during Task 1, Test 2.

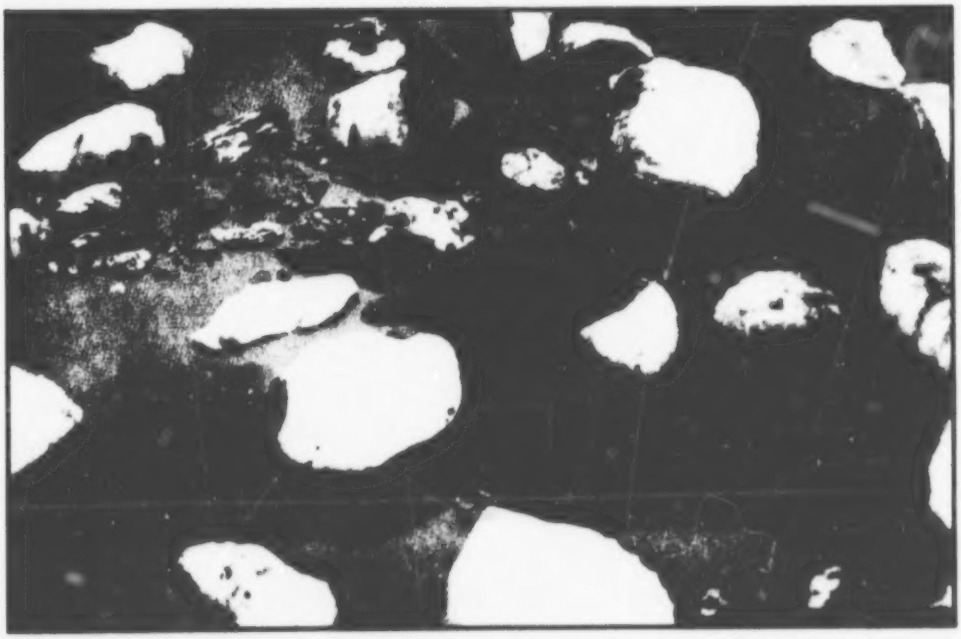


PHOTO 11 Oil spreading among grounded ice pieces during Task 1, Test 2.

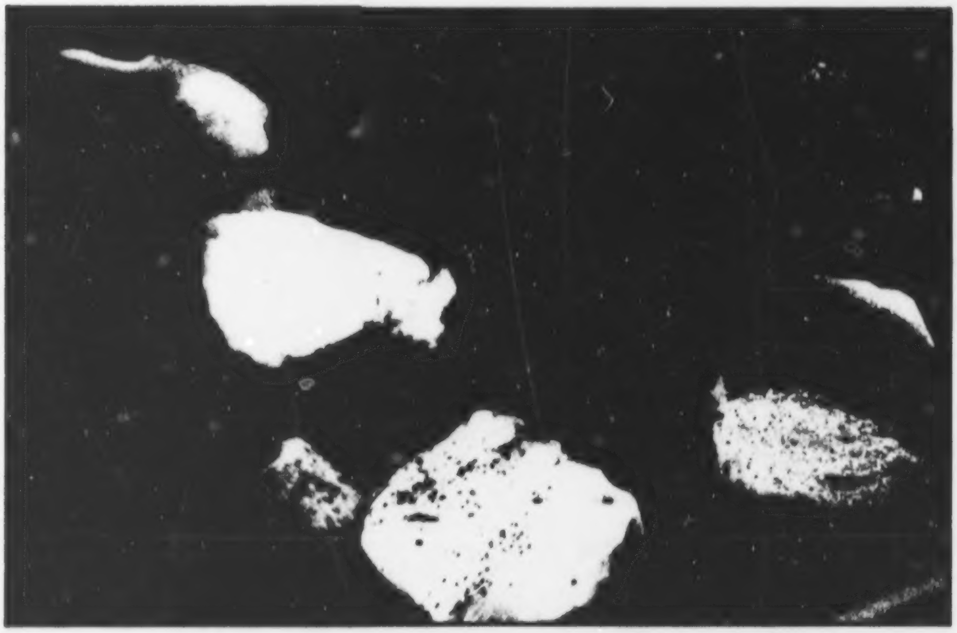


PHOTO 12 Ignition of oil after reaching equilibrium thickness (Task 1, Test 2).

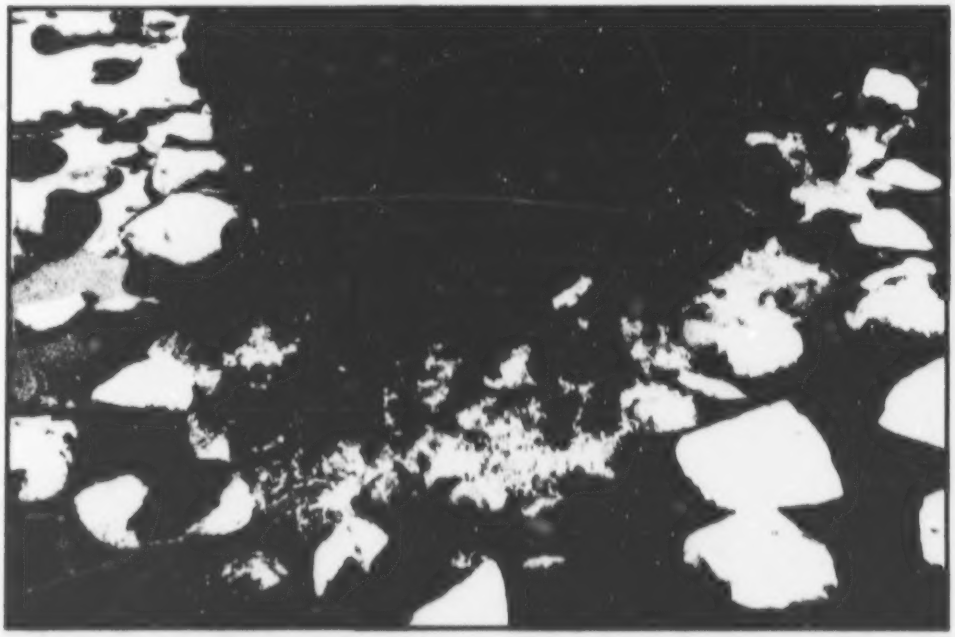


PHOTO 13 Oil burning on water among grounded broken ice pieces during Task 1, Test 2.

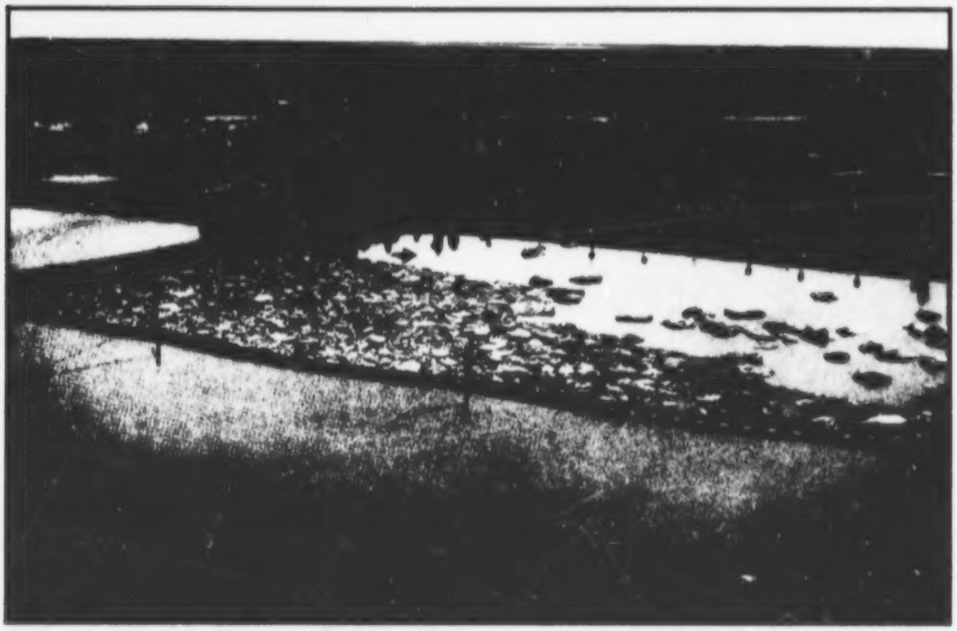


PHOTO 14 View of test pit configuration for Task 1, Tests 3 and 4, with floating ice restrained by containment boom.

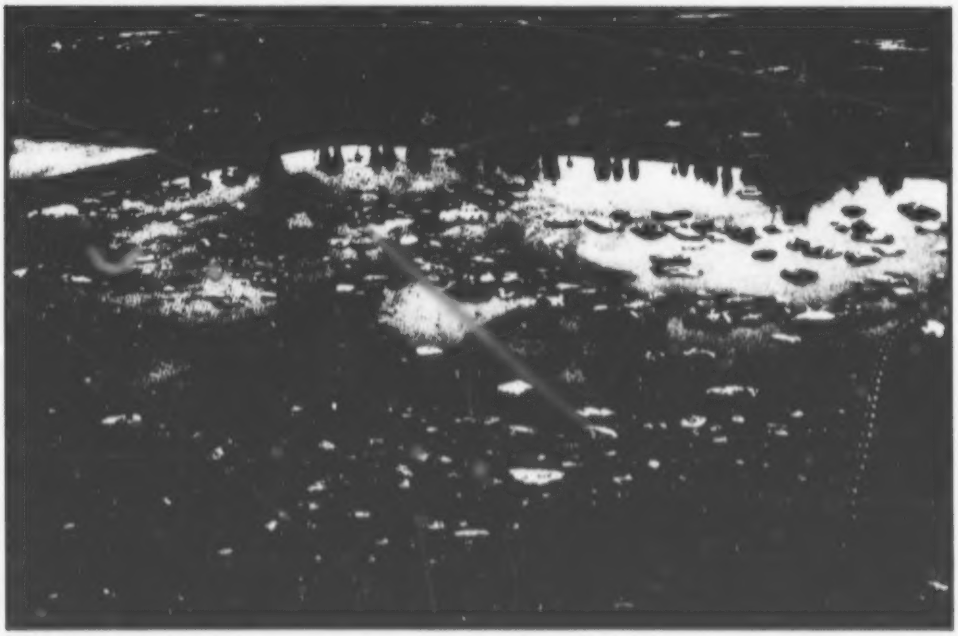


PHOTO 15 Test pit following release of oil in Task 1, Test 3, showing spread of oil among drifting ice pieces.

PHOTO 16 View of oiled ice cakes and brash ice herded against boom prior to Task 1, Test 4.

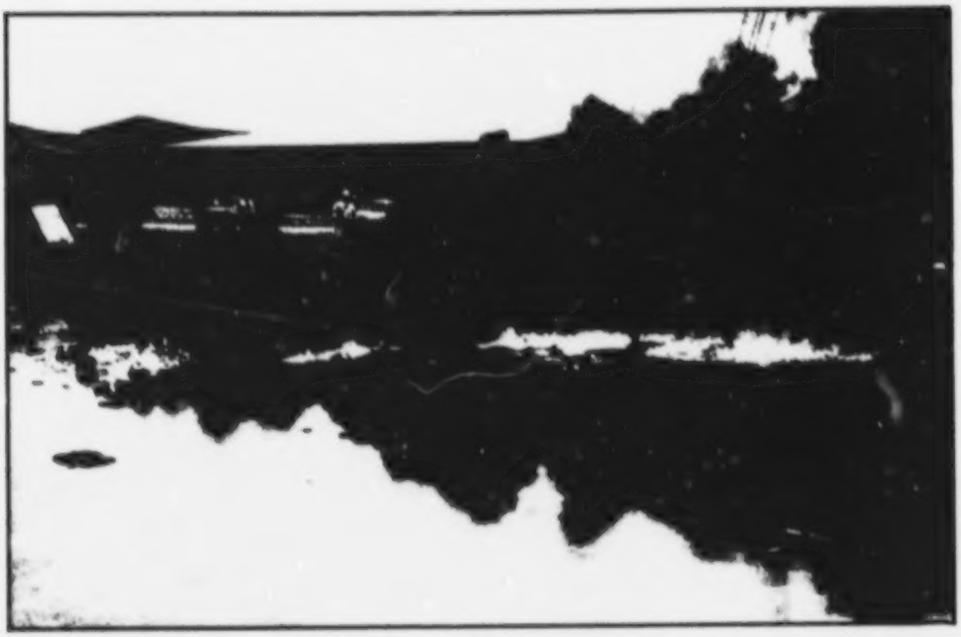


PHOTO 17 Burning oil among drifting ice pieces near the downwind edge of the pit during Task 1, Test 4.

PHOTO 18 Fire burning along downwind edge of the pit with wind herding oil into the fire (Task 1, Test 4).

PHOTO 19 Burning of 1-inch layer of crude oil inside Shell's fire containment boom during Task 2, Test 1.

PHOTO 20 Burn residue inside fire containment boom along with thin film contained by backup boom (Task 2, Test 1).

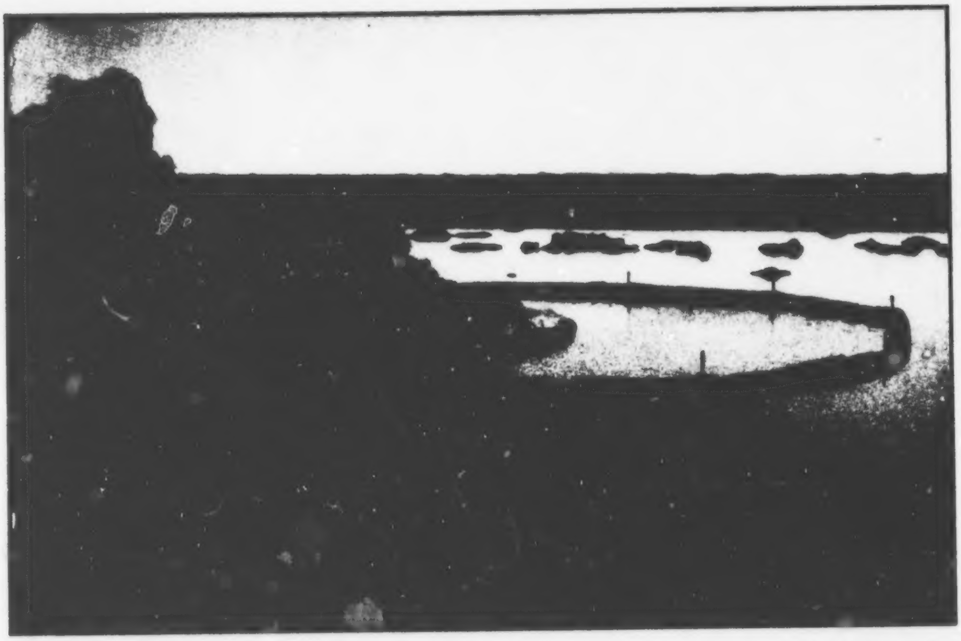


PHOTO 21 Burning of crude oil during 1-hour continuous feed of oil to area enclosed by fire containment boom (Task 2, Test 2).

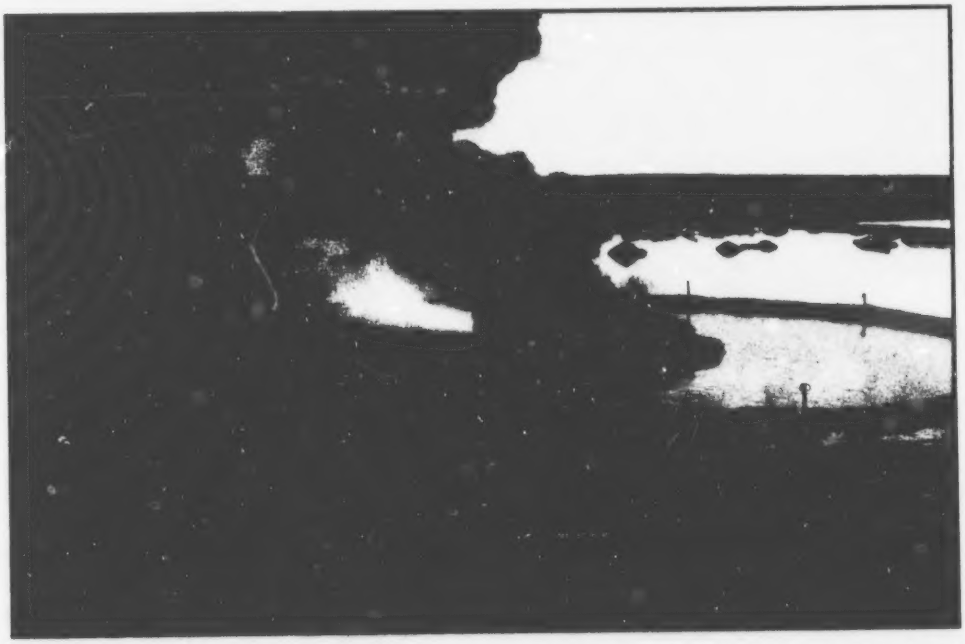


PHOTO 22 Release of oil from inner containment boom after 1-hour burn and subsequent burning of oil at backup boom (Task 2, Test 2).

PHOTO 23 Closeup view of Shell's fire containment boom showing survival of inner Thermoglass layer (Task 2, Test 2).

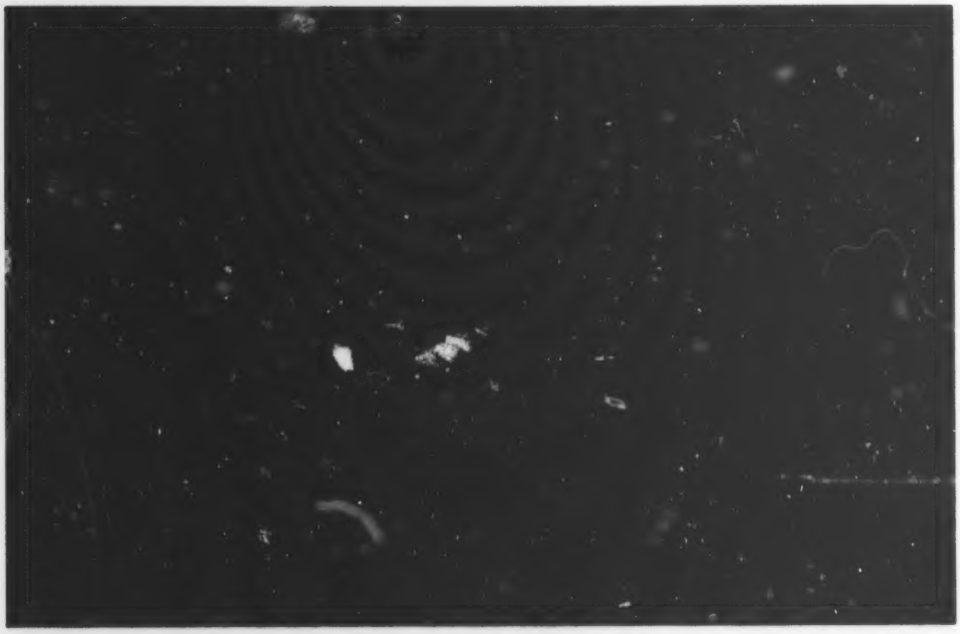


PHOTO 24 Fabrication of fire containment boom at Prudhoe Bay for use in additional burn tests and for Task 6.

PHOTO 25 Outer layer of Thermoglass being fitted over double 3M sorbent boom core already covered with single Thermoglass layer.

PHOTO 26 Location of tie-wraps and chain along bottom of fire containment boom and between inner and outer layers of Thermoglass.

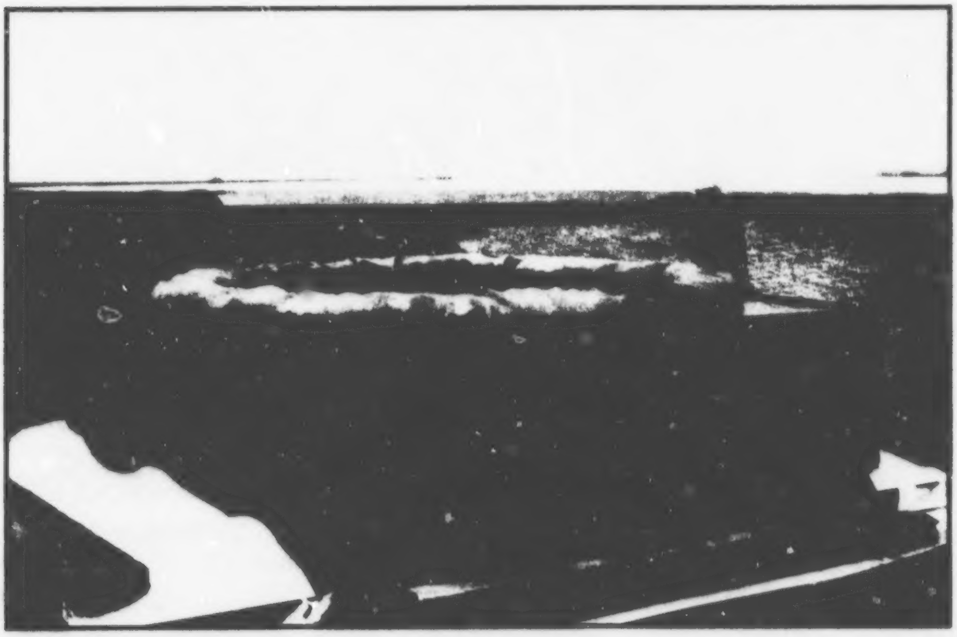


PHOTO 27 Fire containment boom in test tank filled with sea water for additional Task 2 burn tests.

PHOTO 28 Burning of crude oil in fire containment boom during continuous 2-hour burn in test tank filled with sea water.

PHOTO 29 Fire containment boom with burn residue following continuous burn test.

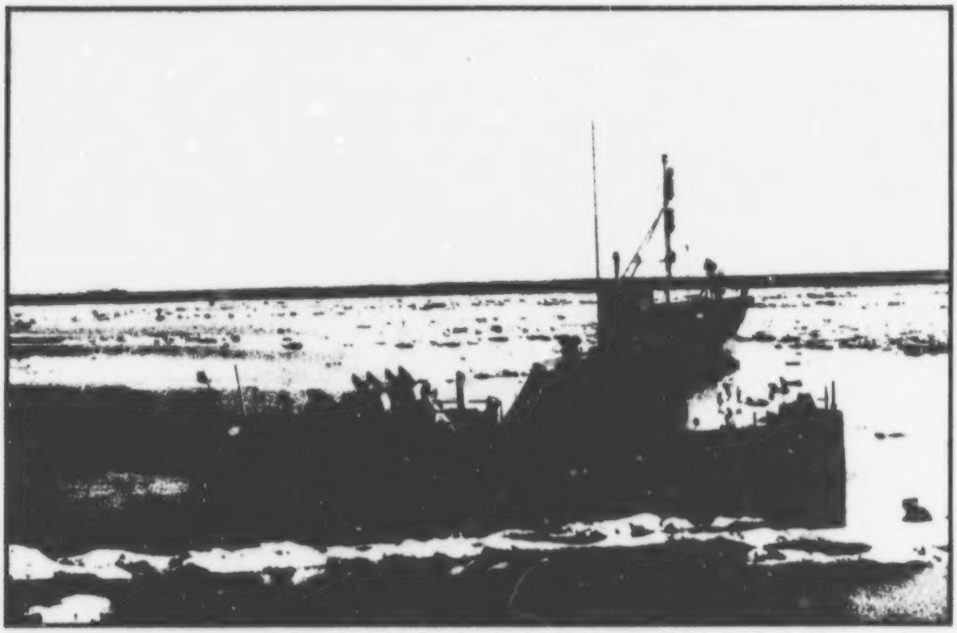


PHOTO 30 *ARCAT* among ice floes off West Dock, Prudhoe Bay (Task 3).

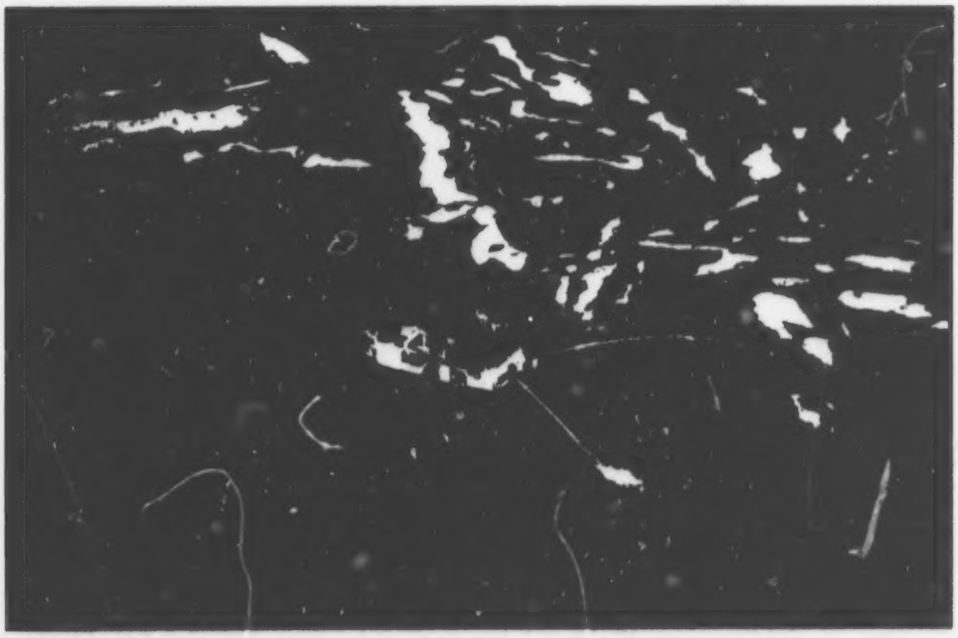


PHOTO 31 *ARCAT* demonstrating dispersant application equipment and fire monitors during Task 3.

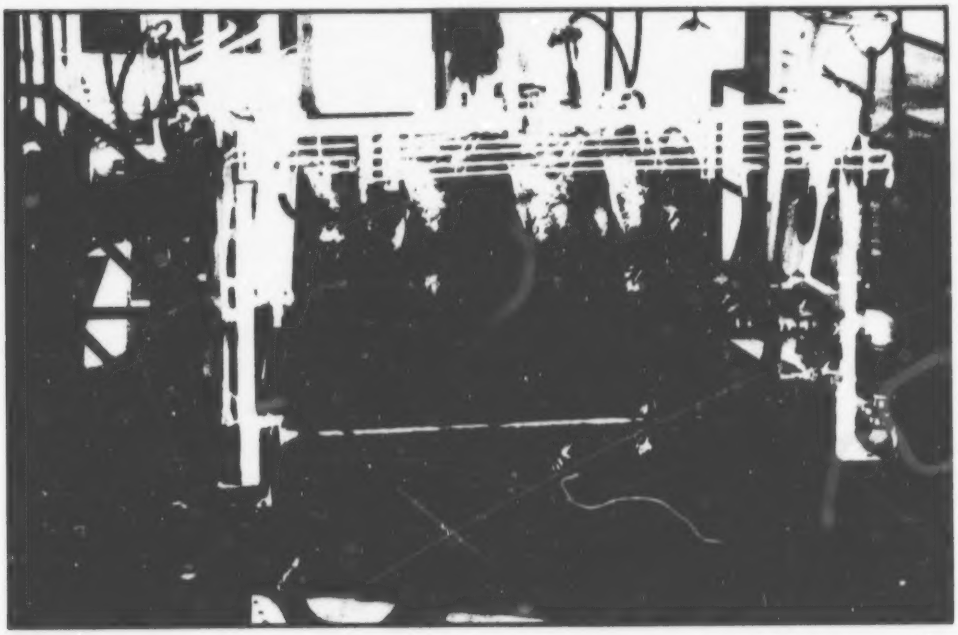


PHOTO 32 Closeup of *ARCAT's* four oleophilic rope mops and pulley assembly at stern of vessel. Weir skimmer with transfer hose is visible in foreground.

PHOTO 33 Rope mops in operation between the hulls of the *ARCAT*.

PHOTO 34 Agency personnel observing *ARCAT* during operation in 3 to 5 oktas ice coverage during Task 3.

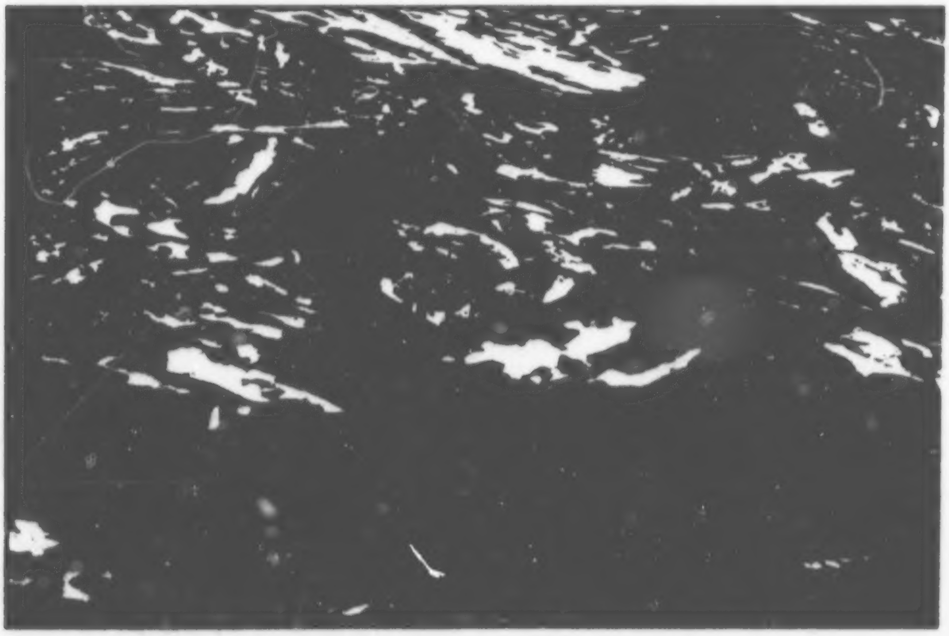


PHOTO 35 Aerial view of *ARCAT* in operation during Task 3.

PHOTO 36 Aerial view of *Arctic Endeavor* being pushed by tugs *Pt. Thompson* and *Pt. Barrow* through close pack ice (6 to 7 oktas) during Task 4.

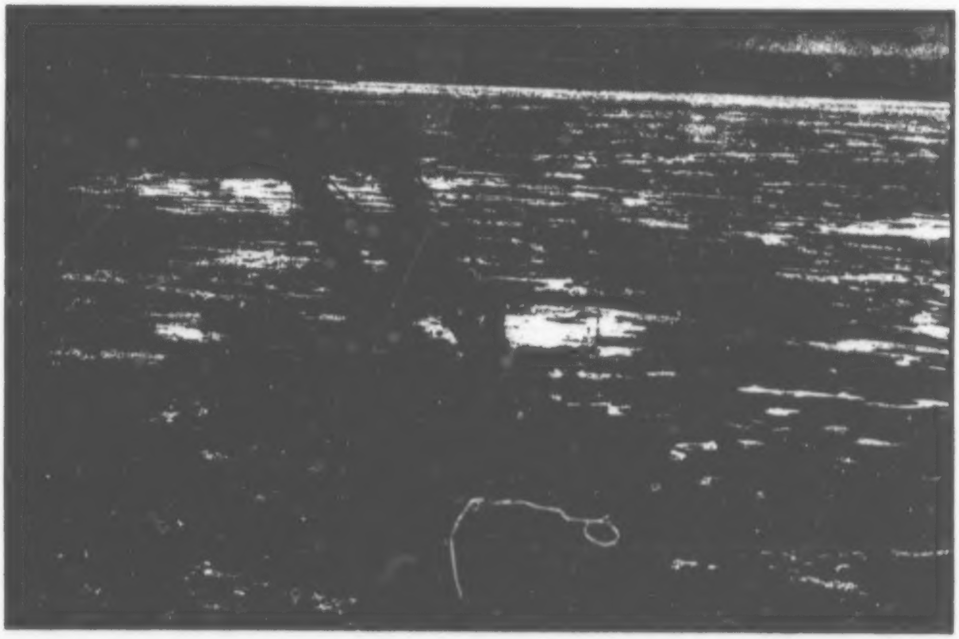


PHOTO 37 Ice-breaking barge *Arctic Endeavor* with tugs in tandem en route to Barter Island (Task 4).

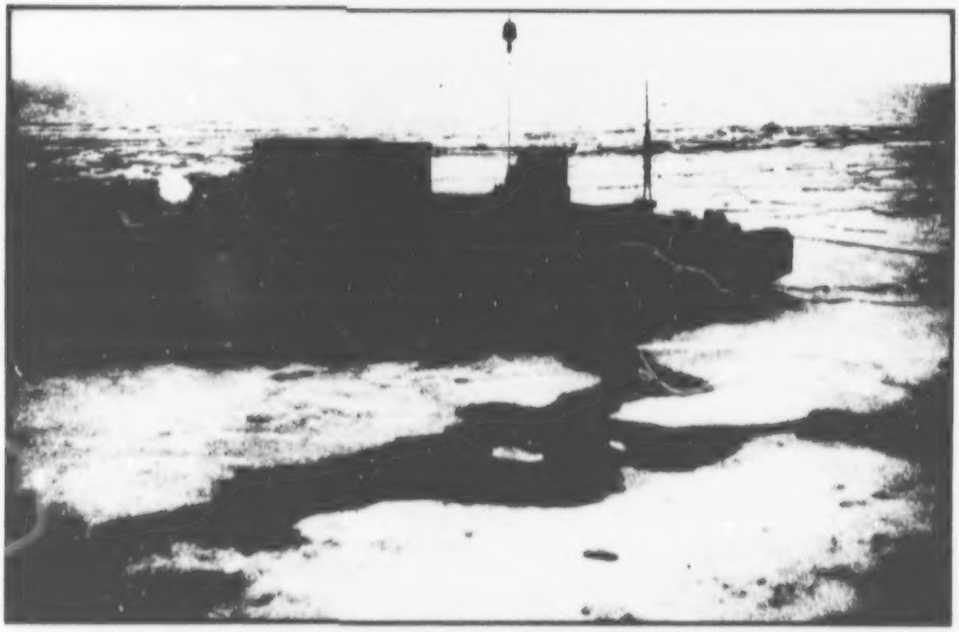


PHOTO 38 *Arctic Endeavor* breaking through 3 to 4 foot thick ice floes (7 to 8 oktas coverage) during Task 4.

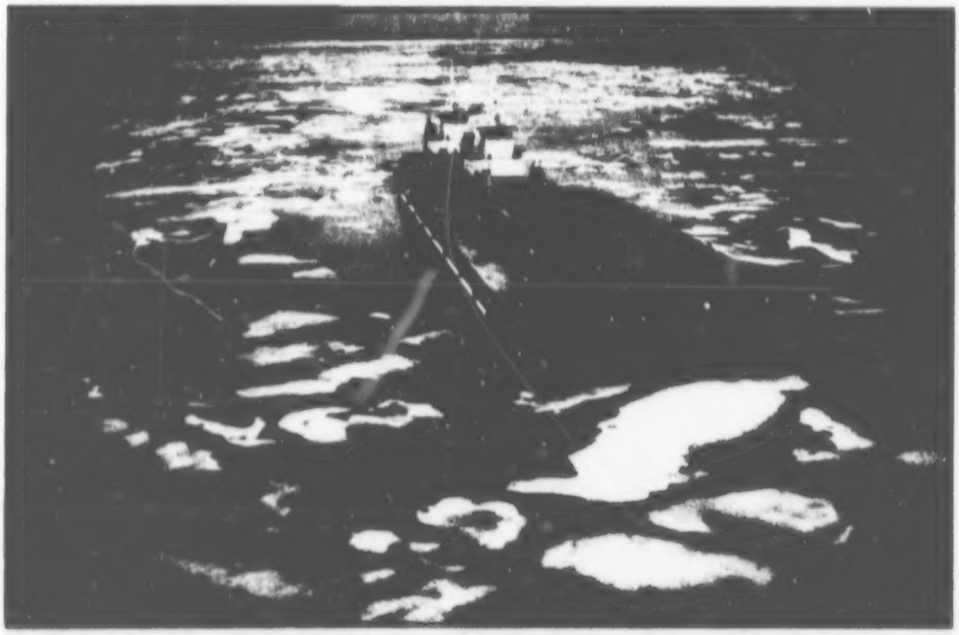


PHOTO 39 Kodiak's *SATCO 10* barge with tugs *Arctic Fox* and *Arctic Bear* moving through 5 to 6 oktas coverage en route from Flaxman Island to Prudhoe Bay (Task 4).

PHOTO 40 Crowley's tug-and-barge train transiting broken-ice field (6 to 7 oktas) en route from Barter Island to Prudhoe Bay (Task 4).

PHOTO 41 Shallow-draft segment of Crowley's tug-and-barge train during Task 4.

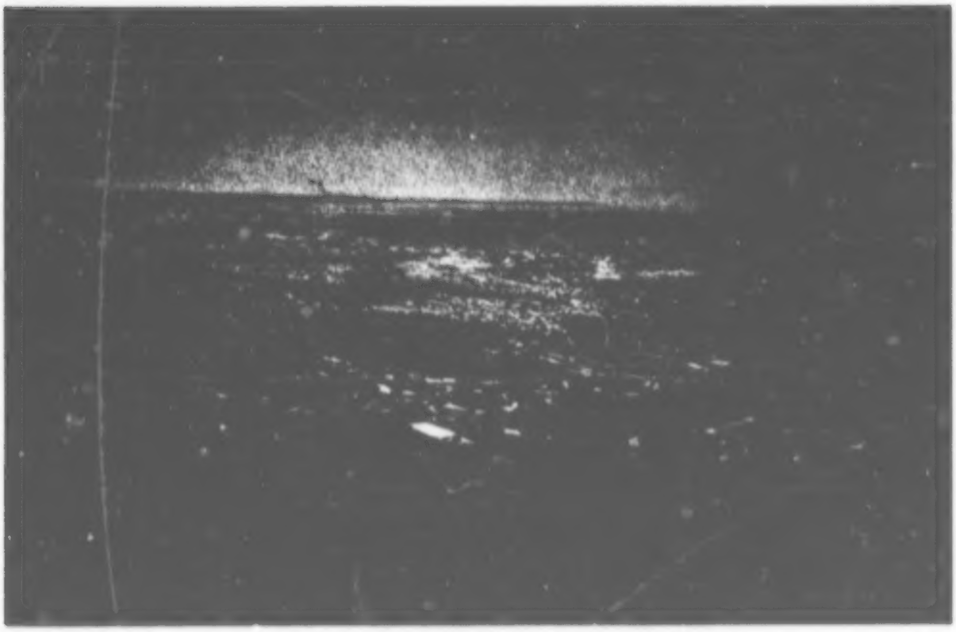


PHOTO 42 Kodiak's *SATCO 10* barge with rope mop skimmers en route to test site during Task 5.

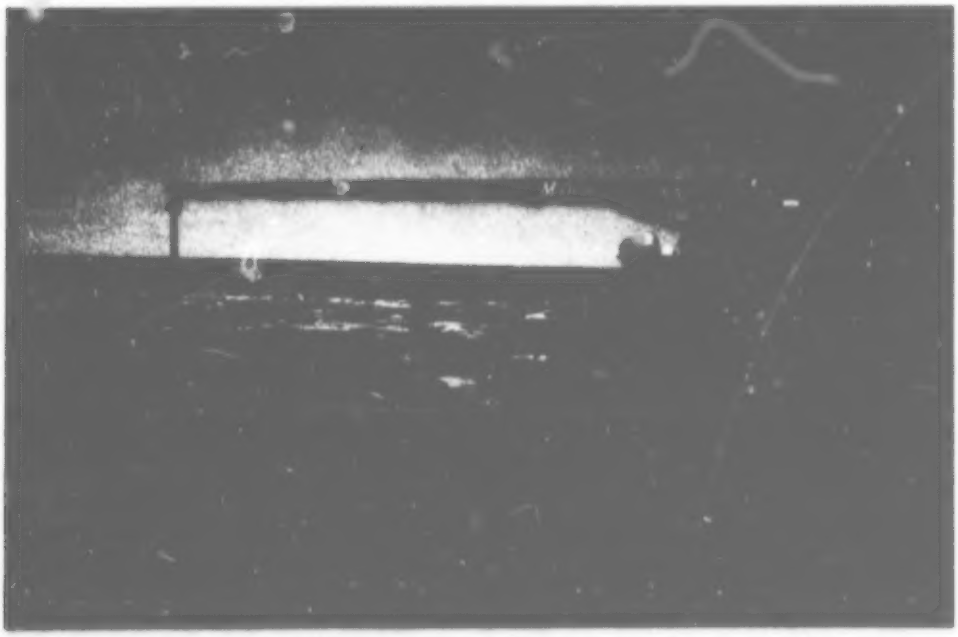


PHOTO 43 Deployment of 100-foot-long rope mop from side of *SATCO 10* barge into broken ice during Task 5.

PHOTO 44 Operation of rope mop alongside barge during Task 5.

PHOTO 45 Fire containment boom deployed in lee of Tern Island during Task 6.

PHOTO 46 Ground-level view of fire containment boom from Tern Island during Task 6.

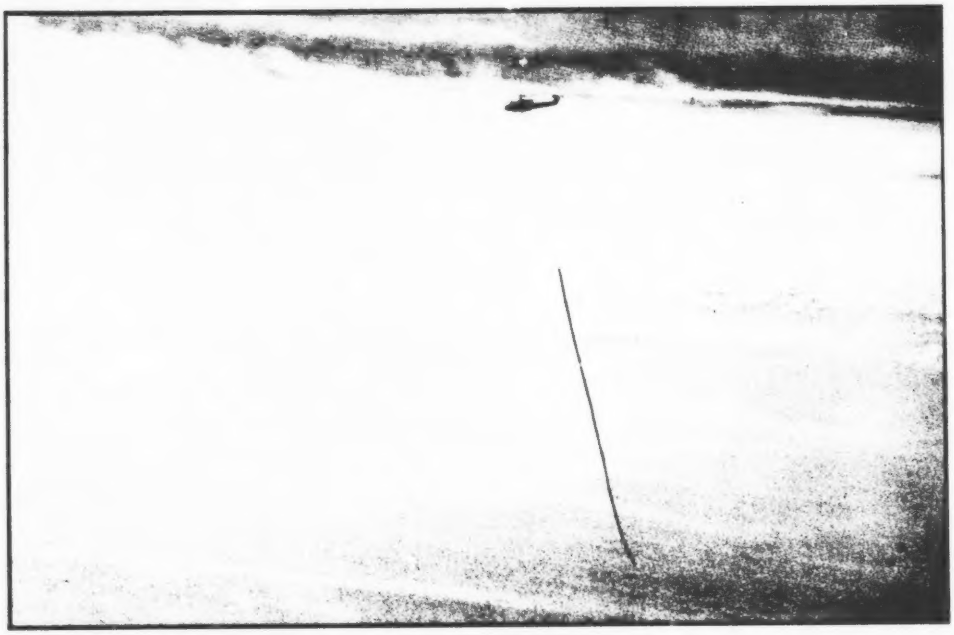


PHOTO 47 Transport of fire containment boom by helicopter to test site for free-floating demonstration in moving ice (Task 6).

PHOTO 48 Fire containment boom drifting in broken ice after helicopter deployment (Task 6, Test 2).

Figure 3. Thermal breakup of Mackenzie River at Norman Wells, May 24, 1983. Note the large areas of open water around broken ice pans, characterizing the thermal breakup. View is looking downstream.

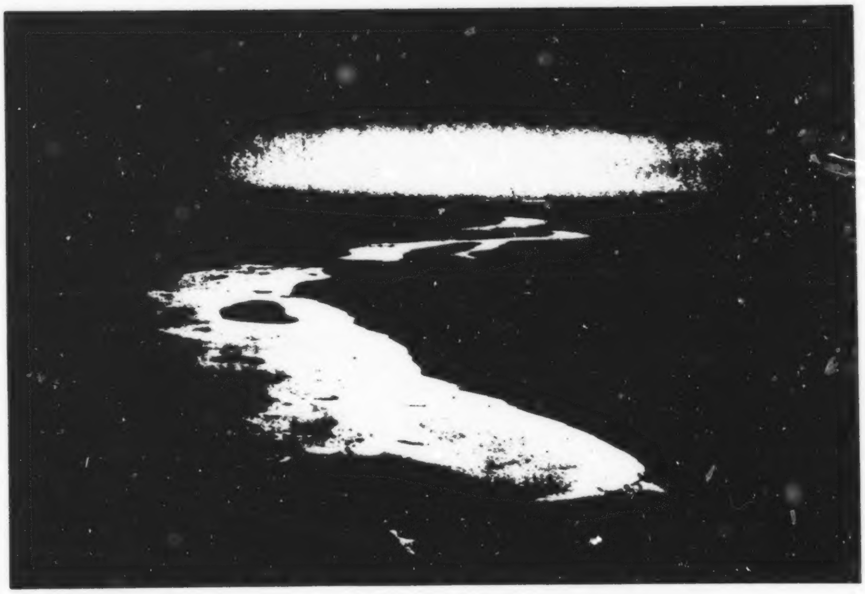
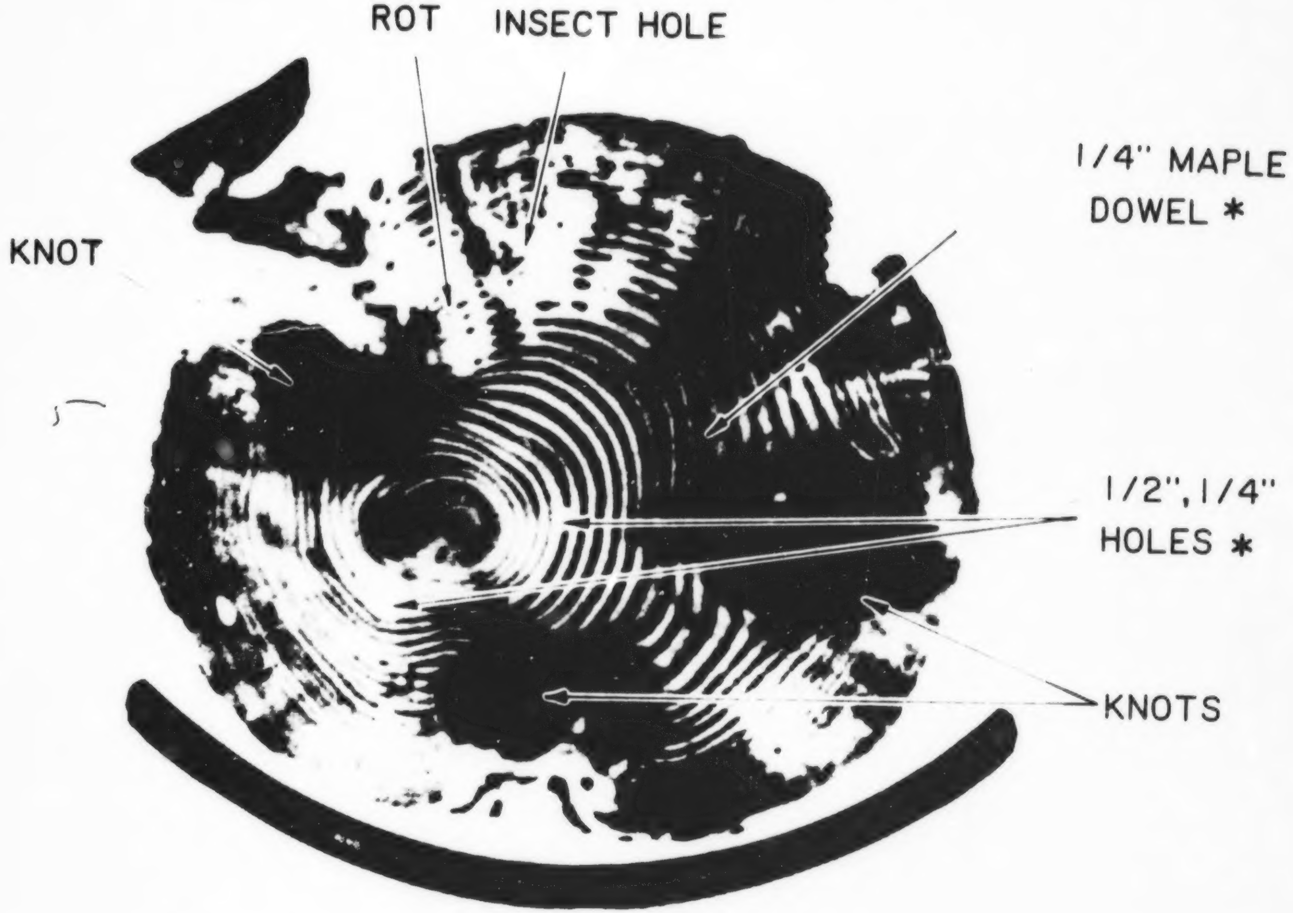
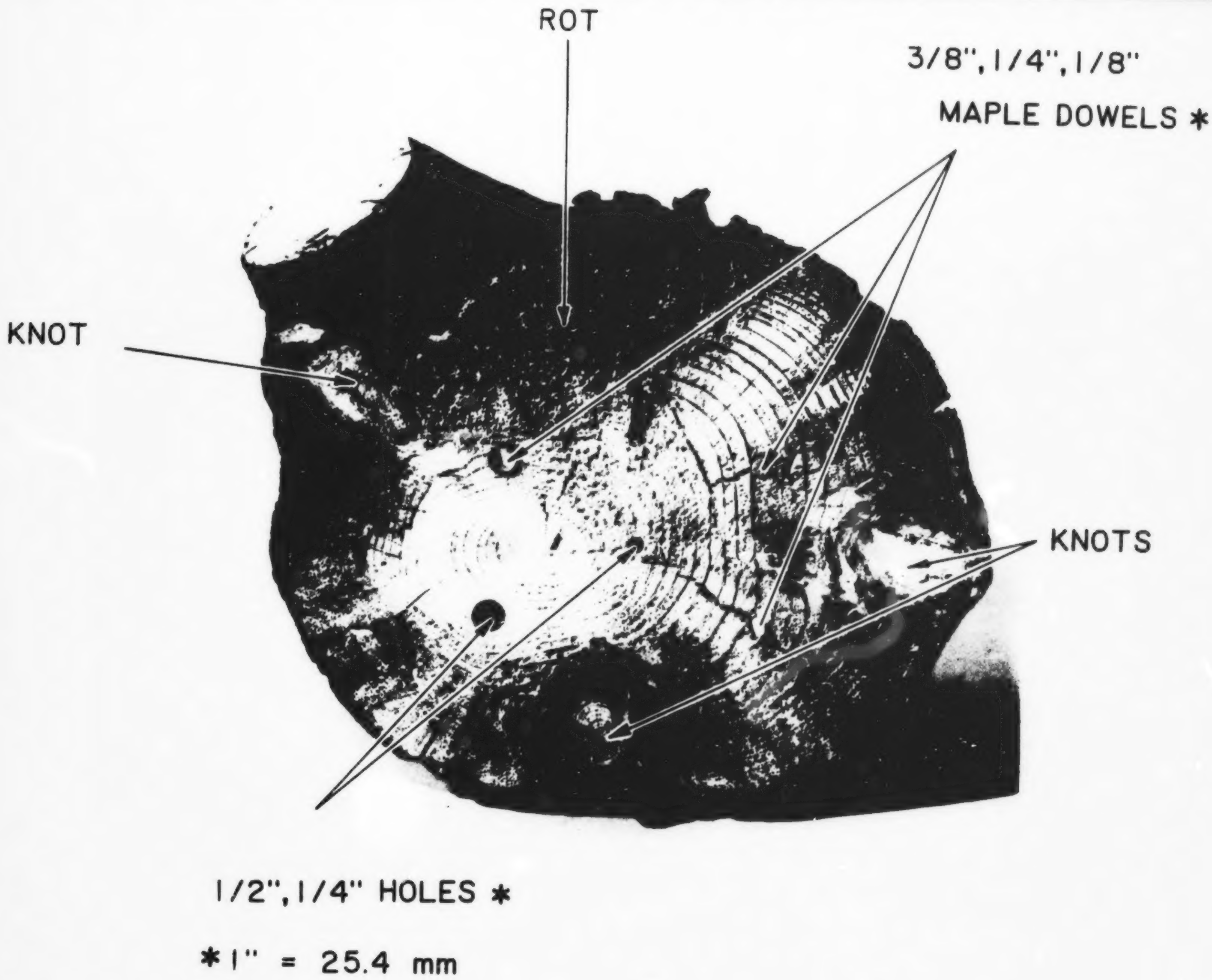


Figure 4. Ice jam breakup of the Mackenzie River at Norman Wells, May 20, 1982. View is looking downstream.

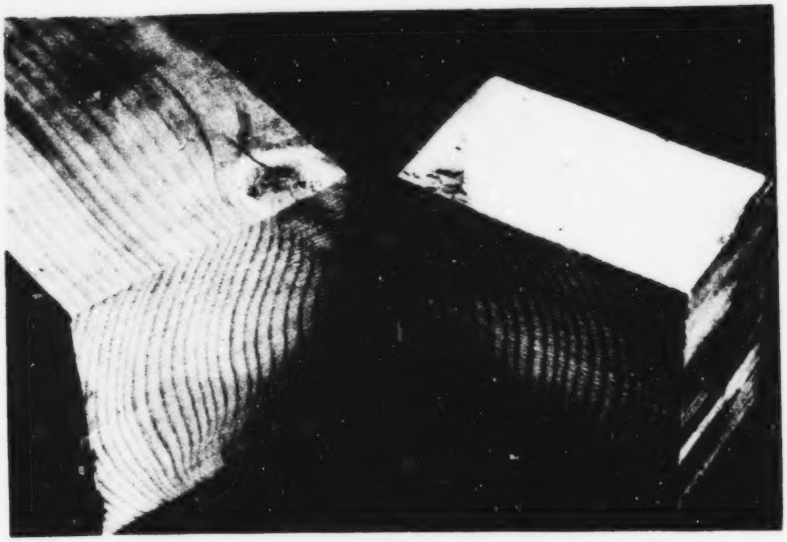

ROT
INSECT HOLE
KNOT
1/4" MAPLE DOWEL *
1/2",1/4" HOLES *
KNOTS

*1" = 25.4 mm

FIGURE 1(a). X-RAY CAT SCAN OF A JACK PINE LOG CONTAINING NATURAL (ROT AND KNOTS) AND ARTIFICIAL (HOLES AND MAPLE DOWELS) DEFECTS. COMPARED WITH THE PHOTOGRAPH ONLY ONE DOWEL COULD BE IDENTIFIED. THE OTHER TWO APPEAR TO HAVE BEEN OVERSHADOWED BY NATURAL DENSITY VARIATIONS IN THE LOG.


ROT
3/8",1/4",1/8"
MAPLE DOWELS *
KNOT
KNOTS
1/2",1/4" HOLES *
*1" = 25.4 mm

GURE 1(b). PHOTOGRAPH OF THE JACK PINE LOG TAKEN AT THE SAME PLANE AS THE CAT SCAN.



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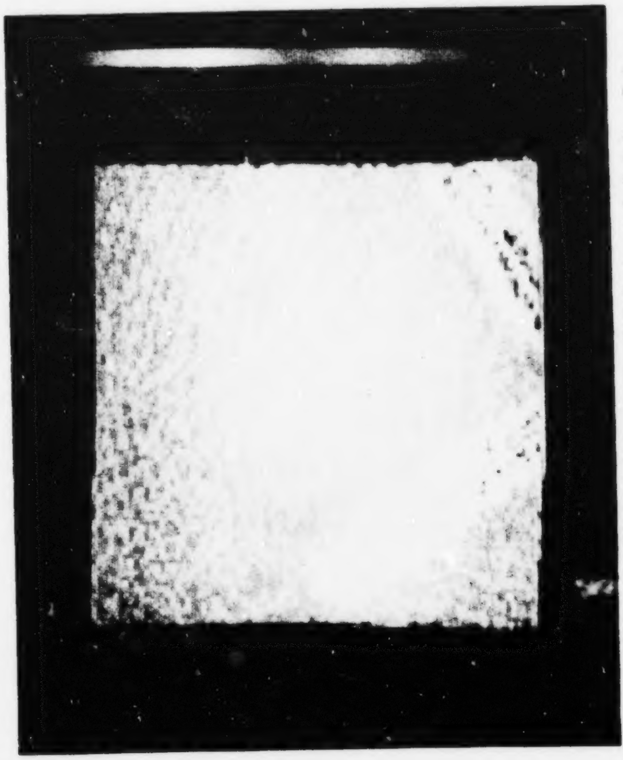

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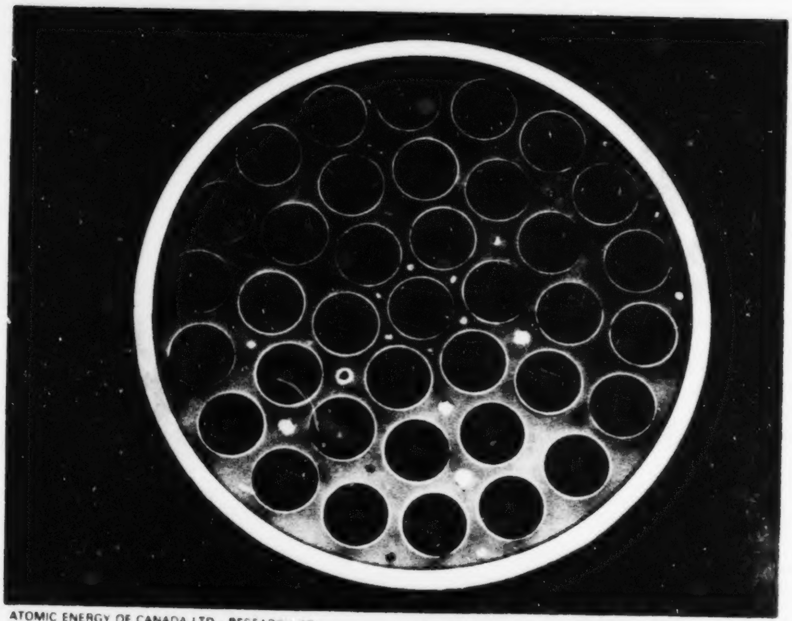
FIGURE 2. PHOTOGRAPH AND CORRESPONDING γ-RAY TOMOGRAPHIC RECONSTRUCTION OF A WOODEN BLOCK SHOWING BOTH GROWTH RINGS AND KNOTS.



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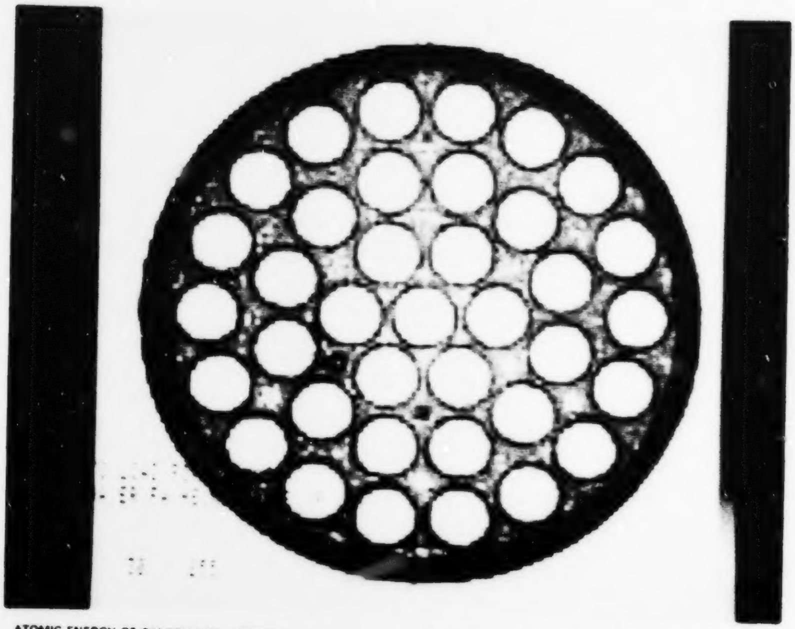
CHALK RIVER ONTARIO

8307-15942-10



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CHALK RIVER ONTARIO

8304-15816-21

FIGURE 3. PHOTOGRAPH AND CORRESPONDING γ-RAY TOMOGRAPHIC RECONSTRUCTION OF A MOCK-UP CANDU FUEL BUNDLE. MATERIAL DENSITIES VARY FROM AN OUTER INCONEL SHELL TO SIMULATED DEFECTS AND EMPTY ZIRCONIUM TUBES EMBEDDED IN PLASTIC. DIFFERENCES ARE REPRESENTED BY THE VARIOUS SHADES OF BLACK AND WHITE. BECAUSE OF THE EXPERIMENTAL NATURE OF THE SCANNER SOME OF THE INNER WHITE AREAS ARE NOT REAL AND THEREFORE NOT REPRESENTATIVE OF LOW MATERIAL DENSITY.

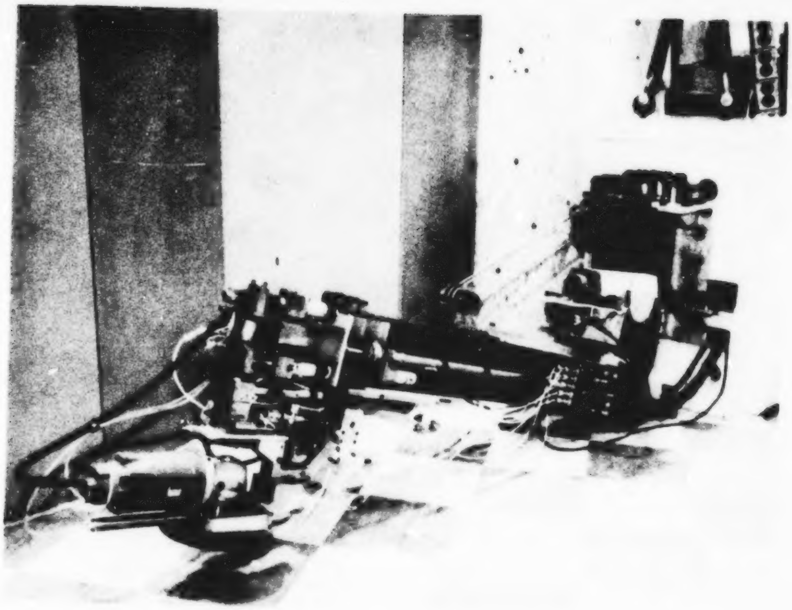
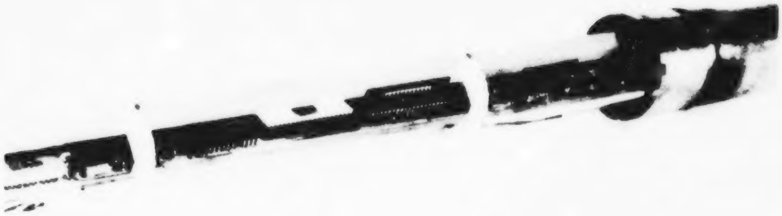


FIGURE 4. REMOTE MULTI-DIRECTIONAL MANIPULATOR WITH VIDEO, CUTTING AND WELDING ATTACHMENTS, USED TO REPAIR HIGHLY RADIOACTIVE LEAKING TUBES AT THE DOUGLAS POINT NUCLEAR GENERATING STATION.



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8308-15986-5

FIGURE 5. MINIATURIZED, FIVE CM DIAMETER, DOWNHOLE PROBE WITH ELECTRONICS PACKAGE PARTIALLY INSERTED IN A 13.8 MPa (2000 psi) STEEL PRESSURE CASING.